PRINCIPLES OF HIGHWAY ENGINEERING

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PRINCIPLES OF HIGHWAY ENGINEERING

BY

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PREFACE TO THE SECOND EDITION

This volume is essentially a modernization of the first edition. The original plan of treatment and order of arrangement have been retained. The text, however, has been thoroughly revised and much of it entirely rewritten. New developments in materials, methods, and basic principles have been included. Several new tables and a number of figures have been added. The number of reading references has been materially increased and the problems at the ends of the chapters are entirely new. The book, therefore, is complete in scope and thoroughly up-to-date in content.

Attention is called to the fact that the treatment of the subject is fundamentally analytical rather than factual. Necessary matters of fact are, of course, included, but primary consideration is given to the objects to be attained, and to the effect of processes and variations on the results. The student is thus trained to analyze a problem and then adapt methods and materials to it rather than merely to imitate work previously done. For the same reason the practicing engineer will find the volume a valuable book of reference.

The author again expresses his sincerest appreciation to everyone who has rendered him assistance. He is especially indebted to Professor E. E. Bauer, Professor J. S. Crandell, Mr. Frank T. Sheets, and Mr. T. T. Wiley.

CARROLL CARSON WILEY.

CHAMPAIGN, ILLINOIS,
April, 1935.

PREFACE TO THE FIRST EDITION

This volume has been prepared for use in college courses in highway engineering. Although intended, primarily, for beginning courses, it will be found of value as an auxiliary and reference book in advanced courses in design and administration.

It has been no small task to condense into suitable dimensions the enormous mass of material available. No attempt, therefore, has been made to make a complete handbook of reference for all of the technical details and processes of road building, or to present a complete discussion or treatise on each of the topics. The plan has been to select material which will set forth or illustrate the various principles and practices in a manner and to the extent that the student can absorb them in the available time. The objects have been to supply the basic ideas and to develop a degree of engineering judgment in the student. It has been left to the classroom to fill in as many other details as may seem necessary, or that time will permit.

The general order of treatment departs from the conventional arrangement. It has been designed to follow a logical sequence of instruction rather than the chronological procedure of actual highway work. Thus, materials are considered separately before taking up their combination into roads and pavements, and the latter are developed before proceeding with the broader problems of design, finance, and operation. In this way, unnecessary repetitions are avoided and each subject is built up from its component parts.

The material has been collected from innumerable sources. Many individuals have rendered valuable assistance by supplying data, making suggestions, and furnishing illustrations. To each of these the author expresses his sincerest thanks and grateful appreciation.

CARROLL CARSON WILEY.

CHAMPAIGN, ILLINOIS,
December, 1927.

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CHAPTER 1

INTRODUCTION

Modern civilization is founded on communication and transportation. Rapid and accurate interchange of information together with the economical and speedy movement of goods and passengers is fundamental to present-day life. The telephone, telegraph, and radio furnish the means of almost instantaneous exchange of ideas. Transportation by rail, water, air, or highway provides the necessary transfer of commodities and people.

Although the highway is not capable of supplanting the other means of transportation, it is, nevertheless, fundamental to them all as well as to the lines of communication. Without the highway it would be impossible to build, maintain, or operate the railroads, water routes, or airways, nor would it be possible to establish and make use of any of the means of communication.

The highway transportation system spreads its branches throughout every city, village, and country side. It links together every industry and reaches every home. Every human endeavor, whether social or commercial, is dependent on it. Practically every commodity journeys over the roads at some stage of its history. In fact, highway transportation is so intimately interwoven with every detail of our daily life that we have come to accept it almost as a primal blessing like air and sunshine. It is so much a part of our existence that we often lose sight of its magnitude and importance and fail to appreciate the problems that are involved in establishing it and maintaining it at the standard demanded.

Highway System.—The highway system of the country is made up of the *rural roads* and the *city streets*. The latter serve the congested population and concentrated activities of

the urban communities. The former traverse the longer distances and scattered operations of the rural districts. Both, however, are essential and integral parts of the whole. The city would perish without the rural roads. The country sections would never prosper and develop without the city street. No scheme of highway development which does not consider the two impartially, which does not provide equitable means of financing both, and which does not secure a thorough coordination of interests will ever succeed in carrying our highway transportation facilities to the perfection required.

Rural Roads.—The total mileage of rural roads in the United States in 1934 is given as 3,065,254. Placed end to end, the length would be sufficient to encircle the earth nearly 125 times. A single trip over them at an average speed of 40 m.p.h. would require almost 9 years of continuous driving. If the average width is assumed to be 50 ft., the land in the right-of-way would amount to practically 29,000 sq. miles, or an area larger than the combined states of Vermont, New Hampshire, Rhode Island, and Massachusetts. At only $10 per acre this right-of-way would have a value of over $185,575,000. If all of these roads were ordinary earth which could be graded at the low cost of $50 per mile, this work would cost nearly $153,300,000. A single dragging would cost over $3,000,000. A light gravel surfacing would cost some $2,000,000,000, while a high-type pavement 20 ft. wide would require an expenditure of over $100,000,000,000.

As compared with the railroads there are about 12½ miles of rural roads for every mile of railroad. In sparsely settled areas the ratio may exceed 20:1 while in industrial states the ratio is lower. For example, Illinois which ranks second in railroad mileage has about 7 miles of highway for each mile of railroad. With respect to area the average for the entire country is practically 1 mile of highway for each square mile of area. In Arizona and Nevada this ratio reduces to about 0.2 mile per square mile. Iowa, a highly developed agricultural state, has about 1.85 miles of road per square mile of land while the commercially developed state of Connecticut has about 2.50.

Based on total population there is an average of about 40 people to the mile of road. Considering only rural population, however, there are about 17 per mile. With respect to motor vehicles the average is 5.26 people per vehicle and about 7.9 vehicles per mile of road.

City Streets.—No one seems to have compiled data concerning city streets; therefore the same comparisons as above cannot be made with any exactness. A very rough estimate places the total mileage of streets in incorporated cities and villages in the neighborhood of 500,000 or about one-sixth of the rural road mileage. Some of the comparisons would be directly in this

TABLE 1-1.—STATE AREAS, POPULATION, AND ROAD MILEAGE JANUARY 1, 1934

State	Land area, square miles	Population		Road mileage		
		Total	Per motor vehicle	State system	Total	Per square mile
Alabama	51,279	2,697,000	13.07	6,500	74,011	1.44
Arizona	113,810	453,000	5.06	2,895	23,238	0.20
Arkansas	52,525	1,872,000	9.95	8,900	74,178	1.41
California	155,652	6,062,000	3.09	14,063	77,085	0.50
Colorado	103,658	1,052,000	3.94	9,236	72,338	0.70
Connecticut	4,820	1,646,000	5.23	2,483	12,031	2.50
Delaware	1,965	241,000	4.71	1,141	3,834	1.95
Florida	54,861	1,554,000	5.56	10,902	29,761	0.54
Georgia	58,725	2,911,000	8.82	8,286	113,196	1.93
Idaho	83,354	447,000	4.65	4,802	40,610	0.49
Illinois	56,043	7,826,000	5.35	13,811	97,157	1.74
Indiana	36,045	3,291,000	4.27	8,378	77,627	2.15
Iowa	55,586	2,482,000	3.92	7,842	103,058	1.85
Kansas	81,774	1,900,000	3.66	9,310	133,154	1.63
Kentucky	40,181	2,648,000	9.00	7,322	62,187	1.55
Louisiana	45,409	2,153,000	9.25	17,631	38,041	0.86
Maine	29,895	802,000	4.78	2,368	20,287	0.68
Maryland	9,941	1,663,000	5.31	3,772	14,907	1.50
Massachusetts	8,039	4,313,000	5.46	1,809	18,770	2.34
Michigan	57,480	5,043,000	4.68	8,843	86,054	1.50
Minnesota	80,858	2,594,000	3.82	11,114	116,075	1.44
Mississippi	46,362	2,047,000	12.43	6,133	60,367	1.30
Missouri	68,727	3,668,000	5.25	16,260	106,047	1.54
Montana	146,131	537,000	4.89	5,013	69,398	0.48
Nebraska	76,808	1,392,000	3.56	7,825	94,739	1.23
Nevada	109,821	93,000	3.28	4,007	23,640	0.21
New Hampshire	9,031	469,000	4.36	3,083	13,014	1.44
New Jersey	7,514	4,193,000	4.95	3,420	19,803	2.65
New Mexico	122,503	434,000	5.65	10,373	33,145	0.27
New York	47,654	12,965,000	5.78	13,947	84,998	1.79
North Carolina	48,740	3,275,000	8.56	10,368	55,125	1.13
North Dakota	70,183	687,000	4.47	7,591	106,842	1.52
Ohio	40,740	6,798,000	4.38	11,839	85,326	2.10
Oklahoma	69,414	2,459,000	5.44	7,162	107,921	1.56
Oregon	95,607	983,000	4.11	4,737	44,007	0.46
Pennsylvania	44,832	9,989,000	6.11	34,020	110,326	2.46
Rhode Island	1,067	702,000	5.15	1,086	3,063	2.87
South Carolina	30,495	1,748,000	10.73	5,954	64,021	2.10
South Dakota	76,868	702,000	4.15	6,000	119,888	1.56
Tennessee	41,687	2,664,000	8.50	7,226	69,590	1.67
Texas	262,398	6,023,000	5.03	19,175	219,196	0.83
Utah	82,184	518,000	5.18	4,624	23,711	0.29
Vermont	9,124	361,000	4.90	1,028	14,040	1.53
Virginia	40,262	2,441,000	7.08	8,971	46,613	1.16
Washington	66,836	1,599,000	3.74	3,553	45,182	0.68
West Virginia	24,022	1,774,000	7.81	4,372	34,869	1.45
Wisconsin	55,256	2,992,000	4.46	10,104	82,979	1.49
Wyoming	97,548	231,000	4.40	3,389	39,805	0.41
District of Columbia	62	495,000	3.30			
Totals and averages	2,973,776	125,889,000	5.26	382,668	3,065,254	1.03

ratio while others would not because of higher costs in the cities.

The total land value of street right-of-way is probably about the same as the total for rural roads. If one-third of the streets have been paved, there has already been spent more than $10,000,000,000 for these improvements. To pave the remainder to present standards would probably cost over $30,000,000,000 more.

Traffic.—It is estimated that the 23,827,000 motor vehicles registered in 1933 traveled about 180,000,000,000 miles during that year. This is equivalent to about 300 trips around the earth's orbit, a journey which would require the earth itself 300 years to make. A single motor car at an average speed of 40 m.p.h. would need almost 514,000 years to make the trip. This traffic mileage amounts to 53,300 vehicles per mile per year on the entire road and street system, or an average daily traffic of 146 vehicles per mile. Many rural roads carry only a small fraction of this average traffic, while city streets and boulevards carry many times as much.

During 1933 the motor cars of the United States consumed about 15,225,000,000 gal. of gasoline with a retail value, including taxes, of at least $2,400,000,000. Oils and greases amounted to some $400,000,000, while tires and accessories added almost $1,000,000,000 more. Including capital charges the total motor-car bill for 1933 probably exceeded $15,000,000,000.

Highway Industries.—Although there has been a sharp decline in automobile manufacturing since the peak of 1929, motor-car building still leads all industries in the amount of capital investment, persons employed, payroll, and value of product. Approximately 3,000,000 people are employed directly in the manufacture, sale, repair, and operation of motor cars. About 1,000,000 more are engaged directly in building, maintaining, and supplying materials for roads and streets. Another 500,000 are engaged in the petroleum industry and other activities related to the highway or motor vehicle. Thus a total of about 4,500,000 or 10 percent of all the gainful workers of the country are engaged in our greatest industry, that of highway transportation.

Road Revenue.—The total revenue for highway purposes is difficult to summarize. The funds are obtained from so many different sources and administered by so many different authorities that it is hard to collect all of the data. In addition, the borrowing of money and the issuance of bonds complicate the

TABLE 1-2.—STATE MOTOR-VEHICLE REGISTRATION, LICENSE FEES, AND GASOLINE TAXES IN 1933

State	Total motor vehicles	License fees		Gasoline taxes			Combined license fees and gasoline taxes per motor vehicle
		Total	Per motor vehicle	Cents per gallon	Total	Per motor vehicle	
Alabama	206,361	$ 2,724,257	$13.20	6	$ 8,033,142	$38.93	$52.13
Arizona	89,496	647,816	7.24	5	2,679,257	29.94	37.18
Arkansas	188,242	1,768,850	9.40	6	5,998,290	31.86	41.26
California	1,958,807	9,866,449	5.04	3	35,217,162	17.98	23.02
Colorado	266,491	2,035,608	7.64	4	5,324,996	19.98	27.62
Connecticut	314,751	7,850,589	24.94	2	4,857,024	15.43	40.37
Delaware	51,099	1,014,333	19.85	3	1,129,577	22.11	41.96
Florida	279,265	4,994,882	17.89	7	14,292,873	51.18	69.07
Georgia	330,147	1,036,241	3.14	6	12,634,513	38.27	41.41
Idaho	96,255	1,401,849	14.56	5	2,283,166	23.72	38.28
Illinois	1,463,050	16,229,327	11.09	3	27,833,011	19.02	30.11
Indiana	770,071	7,846,883	10.19	4	16,288,646	21.15	31.34
Iowa	632,292	10,695,407	16.92	3	9,372,343	14.82	31.74
Kansas	517,987	3,056,837	5.90	3	7,771,369	15.00	20.90
Kentucky	294,547	4,174,076	14.17	5	8,316,017	28.23	42.40
Louisiana	232,688	4,052,816	17.42	5	8,155,436	35.05	52.47
Maine	168,173	2,909,237	17.30	4	4,126,640	24.54	41.84
Maryland	313,274	3,581,251	11.43	4	7,207,749	23.01	34.44
Massachusetts	789,788	6,508,343	8.24	3	16,377,352	20.74	28.98
Michigan	1,077,209	18,560,314	17.23	3	19,485,320	18.09	35.32
Minnesota	679,243	6,366,982	9.37	3	10,213,636	15.04	24.41
Mississippi	164,688	1,870,396	11.36	6	6,100,948	37.04	48.40
Missouri	698,362	9,356,828	13.40	2	9,081,135	13.00	26.40
Montana	110,245	1,070,104	9.70	5	2,751,303	24.96	34.66
Nebraska	390,651	1,721,834	4.40	4	7,706,261	19.73	24.13
Nevada	28,324	299,634	10.58	4	695,653	24.56	35.14
New Hampshire	107,631	2,167,421	20.14	4	2,349,849	21.83	41.97
New Jersey	845,734	15,377,843	18.18	3	16,470,647	19.47	37.65
New Mexico	76,643	666,748	8.70	5	2,281,892	29.77	38.47
New York	2,240,757	42,318,407	18.88	3	43,392,946	19.37	38.25
North Carolina	382,308	5,356,126	14.01	6	14,773,282	38.64	52.65
North Dakota	153,889	1,382,008	8.98	3	1,924,830	12.51	21.49
Ohio	1,554,314	17,677,551	11.37	4	33,939,981	21.84	33.21
Oklahoma	451,712	3,382,455	7.49	4	10,078,645	22.31	29.80
Oregon	239,410	5,337,137	22.29	5	6,343,891	26.50	48.79
Pennsylvania	1,635,019	29,184,792	17.85	3	31,059,378	19.00	36.85
Rhode Island	136,261	2,198,342	16.13	2	1,884,682	13.83	29.96
South Carolina	162,735	2,503,367	15.38	6	6,679,326	41.04	56.42
South Dakota	169,249	1,459,027	8.62	4	3,346,015	19.77	28.39
Tennessee	312,180	2,940,010	9.42	7	12,979,882	41.58	51.00
Texas	1,201,762	12,747,489	10.61	4	28,479,350	23.70	34.31
Utah	100,362	797,598	7.95	4	2,189,714	21.82	29.77
Vermont	73,576	2,072,717	28.17	4	1,766,152	24.00	52.17
Virginia	344,704	6,090,279	17.67	5	11,082,040	32.15	49.82
Washington	427,406	2,482,758	5.81	5	10,863,214	25.42	31.23
West Virginia	226,985	3,837,922	16.91	4	4,927,728	21.71	38.62
Wisconsin	670,797	9,768,006	14.56	4	15,169,426	22.61	37.17
Wyoming	52,560	679,411	12.93	4	1,405,415	26.74	39.67
District of Columbia	149,790	625,508	4.18	2	2,082,346	13.90	18.08
1933 totals and average	23,827,290	$302,694,065	$12.70	3.65	$519,403,450	21.80	$34.50
1932 totals	24,115,129	326,646,373	13.55	....	514,138,900	21.32	34.87
1933 increase or decrease	−287,839	−23,952,308	−0.85	....	+5,264,550	+0.48	−0.37

bookkeeping. It is especially difficult to obtain reliable summaries on city revenues for street purposes.

Rural highway funds are obtained from direct taxes and special taxes on vehicles, drivers, gasoline, etc. In 1932 a total of $1,001,150,000[1] was collected from the motor cars of the country in license fees, gas taxes, and other levies. In 1933 the sum was $1,137,872,000.[2] On the same basis of increase the figures for 1934 would be roughly $1,260,000,000. These funds were originally for road work but since 1931 heavy diversions to other purposes have reduced the actual funds available in many places. In 1933 the official diversion of gasoline taxes amounted to over $44,000,000, with the 1934 figures still higher. Probably the total revenue from motor vehicles in 1934 that found its way into the road funds did not exceed $1,100,000,000.

To the foregoing should be added the annual local road and bridge taxes, poll taxes, special assessments, etc. Exact figures for these items are not available. A rough estimate, however, would be $400,000,000, giving a total of about $1,500,000,000. To this can be added the federal aid funds and the special federal allotments for employment during 1933–1934, making a probable grand total of over $1,800,000,000. This sum, taken alone, seems enormous but it amounts to only about 1 ct. per mile of our motor travel or about the same as our net gasoline bill.

Safety.—Every means of transportation contains potential elements of danger and provision must be made to minimize their effects. Ocean and railway travel have achieved an enviable record for low casualties. Highways, on the other hand, show a distressingly large number of fatalities. If our many precarious roads, our comparative indifference to safety in vehicle maintenance, the slight restrictions placed upon drivers, and the innumerable crossings and recrossings of traffic lines are considered, it is rather surprising that accidents are no more frequent than they are.

Table 1-3[3] shows the number of fatalities in the United States for each year since 1923. In addition to the fatalities, it is estimated that 30 to 35 people are injured for every one killed. Hence each year nearly a million persons are more or less seriously hurt. The reduction of the number of injuries and deaths due to

[1] *Public Roads*, Vol. 15, No. 8, p. 185. October, 1934.

[2] "Automobile Facts and Figures," 1934 ed., p. 48.

[3] "Accident Facts," 1934, p. 32, National Safety Council, Chicago.

the motor car involves the betterment of the highway, the improvement of the vehicle, the training of the driver, and development of proper traffic regulations. These are all problems for the engineer, and if he does not solve them no one will.

TABLE 1-3.—MOTOR-VEHICLE DEATHS AND DEATH RATES
(*National Safety Council*).

Year	Total	Collision				Non-collision	Per 100,000 population	Per 10,000 motor vehicles	Per million-vehicle-miles
		Pedestrian	Other vehicles	Trains and street cars	Fixed objects				
1913	4,227	......	......	.....	.....	.....	4.4	30.7	
1918	10,723	......	......	.....	.....	.....	10.4	16.8	
1923	18,394	......	......	.....	.....	.....	16.5	12.1	
1928	27,996	11,420	5,260	2,711	1,250	7,360	23.3	11.4	17.4
1930	32,929	12,900	7,030	2,311	1,960	8,730	26.7	12.4	17.4
1931	33,675	13,370	7,720	2,149	2,590	7,850	27.1	13.0	17.0
1932	29,451	11,490	6,820	1,838	2,300	7,000	23.6	12.2	16.1
1933	31,363	12,840	7,180	1,755	2,680	6,900	24.9	13.2	17.1
1934	36,101	14,480	8,970	1,789	3,250	7,610	28.5	14.4	18.4
1935	36,369	14,350	9,450	1,840	3,130	7,600	28.5	13.9	17.4
1936	38,089	15,250	10,400	1,966	3,340	7,130	29.7	13.5	16.4
1937	39,643	15,450	11,260	2,053	3,750	7,140	30.7	13.4	15.9
1938 (est.)	32,400	12,500	9.570	1,830	3,050	5,450	24.9	11.0	12.9

Road Improvement.—Roads are laid out or opened as the demand for them arises. The development of new territory calls for additional rural roads. In this manner, the rural highway system has grown to its present size, and it will continue to grow in the same way.

At the outset most roads are little more than mere rights-of-way. As traffic grows, better drainage and grading must be provided. With still greater traffic comes the necessity of surfacing and later paving with all the accessories of the high-grade modern highway. Thus the development and improvement of the highway system as a whole are always a progressive process.

The introduction of the motor car caused traffic to increase enormously in a very short time. The demands of this traffic have been vastly in excess of the ability of the roads to meet them. The greatest part of present roadwork is concerned,

therefore, with the improvement of an existing system and the individual roads which make it up, rather than the building of a

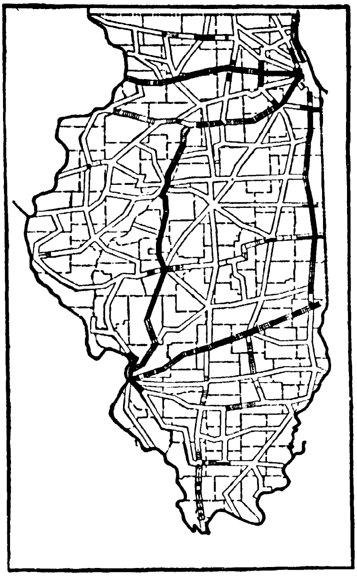
FIG. 1-1.—A road of yesterday.

FIG. 1-2.—A road of today.

new system. This process of improvement, however, calls for many sections to be relocated or for new extensions; hence in a technical sense the problems cover all phases of location, design, and construction.

Illinois State System of High Type Pavements

JANUARY 1, 1921



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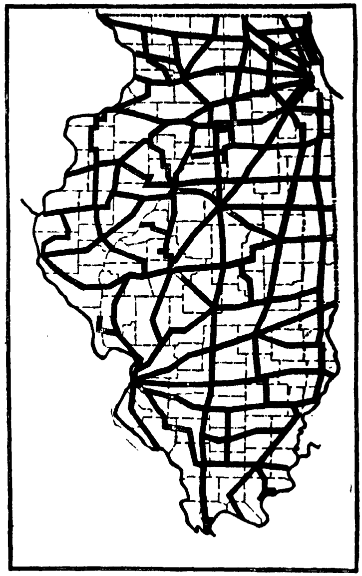

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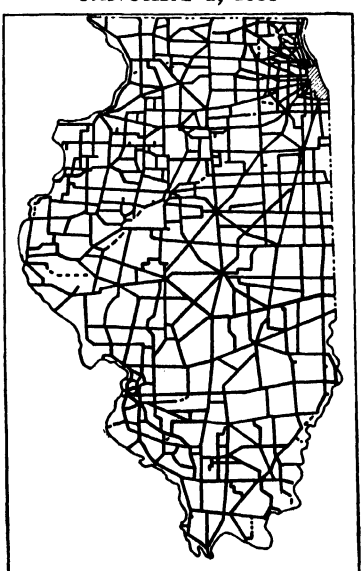

WORK COMPLETED

Period	Pavement, miles	Grading, miles	Bridges, No.
Prior to Jan. 1, 1921...	1,194	700	743
Jan. 1, 1921 to Jan. 1, 1927......	4,840	1,247	1,016
Jan. 1, 1927 to Jan. 1, 1935......	8,390	2,117	2,489
Totals......	14,424	4,064	4,248

Construction Records

1230 miles of pavement in one year
63 miles of pavement in one week
2669 feet of 18-ft. pavement in one day with one mixer.

FIG. 1-3.—An example of progress in road building; accomplished through moderate taxation on motor vehicles and the concentration of authority in a single organization.

Although the general development of the system is naturally progressive, the sudden demands of traffic, accompanied by comparatively generous and yet limited funds, have introduced many problems. Not the least of these is the selection of the roads on which to do the work. Every citizen naturally thinks that his particular road should be the first one improved. Unfortunately, however, all cannot be first, and many cannot be included in the program for many years. The only logical and equitable scheme, therefore, is to choose those roads which will *render the greatest service to the largest number at the lowest cost.* This is the fundamental law of all public improvements.

The natural order of events is for each individual road to develop from a trail to a paved way through a succession of stages extending over a considerable period of time. The sudden demands of traffic, however, are compelling many roads to make the transition almost at once. No matter which plan is being promoted, care must be taken that the scheme proposed is not merely a move to exploit some material, accommodate some contractor, or satisfy some political enterprise.

The charge has been made that the funds are spent on the *intercity* road for the benefit of the city man and to the detriment of the farmer. Almost invariably these intercity roads carry the most traffic since they serve both the cities and the rural district through which they pass, in which there are probably as many residents as would be reached by the same length of road placed elsewhere. Therefore their improvement renders the greatest service to the largest number. Furthermore, these roads may be already absorbing the greater part of the local taxes simply because the traffic on them demands it. In a purely rural community this condition often works a hardship on the local people, and any scheme of improvement by other than their own funds brings instant relief and benefit. For example, a certain township in Illinois was spending more than 75 percent of its road and bridge tax on one stretch of road on which less than 5 percent of the traffic originated in the township. When this road was taken over by the state, the township was relieved of the burden and consequently, without increasing the taxes, had four times as much money as before to apply to the roads serving its own people.

The counterpart to the charge that the cities instead of the country are benefiting from present road improvement is the

demand to improve the *farm-to-market* road. A careful consideration of this idea leads to the same conclusion as before. Every rural road is a farm-to-market road. Some roads, however, serve more farmers than others. Thus the main road into the market center may serve a large number of farms, while the side road reaches to but one or two. Therefore, with the impossibility of improving all the roads, the greatest farm-to-market service is rendered by improving the road used by the largest number. This main farm-to-market road is normally an intercity road as well; hence both urban and rural considerations lead to the improvement of the same road.

The second basic law of road improvement, therefore, is: *First improve that road on which traffic is the greatest or will be the greatest when the improvement is completed.*

Street Improvement.—City streets are improved somewhat differently from the country roads. New streets are laid out as the city grows. Formerly, the street arrangement was entirely in the hands of those making the subdivisions, with the result that street plans were far from adequate. City *zoning* and city *planning* are doing much to remedy the defects and prevent their repetition.

The streets may be paved at once when first laid out but usually they are only graded and surface drained. Paving is postponed until the section begins to build up and the local residents demand it, except in cases where arterial traffic requirements may cause the city to take the initiative. Often a trunk highway enters a city through an undeveloped area. Local conditions may not call for pavement, the city cannot finance the improvement except by heavy assessments on the property, and, thanks to ill-conceived legislation, the state authorities formerly were often prohibited from participating. Consequently there frequently resulted a sort of "no-man's land" where nothing could be done, and the arterial routes of highway transportation were disfigured and often obstructed with unpaved gaps lying within the corporate limits of the municipality. Fortunately, these defects have been corrected. Restrictions have been removed from the state activities in most places. In most states a portion of the gas-tax funds is allotted to the cities; hence it is now possible to improve the entrance of trunk highways into the cities both promptly and properly and without heavy assessments on adjacent property.

Highway Engineering.—Highway engineering is that branch of civil engineering which treats of the economics, design, construction, maintenance, and operation of routes for vehicular and pedestrian travel. The uniting of all these various factors into a harmonious whole is *highway administration* in the broad sense.

The economic and technical problems of highway engineering cover an extremely wide field and are fully as complicated as those of any other branch of engineering. Lack of competent engineering in the past accounts for many of our road and street troubles of today. The work of the future will demand the highest engineering skill. Furthermore, highway engineering is unique in that it always deals at first hand with the public. Every individual is vitally and directly interested in the highway problem. Consequently the highway engineer, whether serving as a public officer or engaged in private practice, finds himself in direct contact with the people of the locality both individually and collectively. This calls for a degree of tact, diplomacy, technical skill, integrity, and sociological knowledge not demanded by any other branch of the engineering profession.

The cost of the engineering work incident to road and street improvement runs into very considerable sums. There is somewhat of a tendency on the part of the public to look on these charges as unnecessary or at least excessive. The fact remains, however, that it is only where reasonable sums have been spent on competent engineering that the highway dollar has fulfilled the requirement of *the greatest service at the lowest cost.*

A commercial engineering concern finds that to pay current prices for materials, rents, help, etc., requires that it receive from 6 to 8 percent of the cost of construction in order to make a profit. Public bodies can sometimes apparently go under this percentage on account of freedom from rents, etc. Some municipalities are apparently "getting by" with 3 to 4 percent, but in most cases the engineering force is underpaid, the work not well done, or the bookkeeping incomplete. Well-organized state highway departments doing considerable work are finding that their total engineering and administrative costs run from 6 to 8 percent, with the purely technical engineering work incident to making the surveys, plans, and supervising construction ranging from 4½ to 6½ percent.

If all factors are taken into consideration, it is probably safe to say that 7 percent is a conservative normal average cost of the

engineering work incident to road improvement. Taking this rate as applying only to the improvement expenditures of $1,800,000,000 a year, the annual engineering costs amount to about $126,000,000 per year. Although this seems an enormous sum, it is by no means unreasonable. In fact, it is lower than it should be. No other form of expert and fundamental service is rendered at so low a relative cost. Legal expenses, for example, are far greater in proportion.

Economics.—The ox cart in the country, the "one-hoss shay" in the city, with a dirt roadway for both, was the standard of our great-grandparents. Anything more than this was an almost unheard-of luxury. "A century of progress," however, has brought us the motor car as the standard vehicle and with it an "all-weather" surface at the bottom of the scale of the magnificent system of motor highways of today. It is therefore fundamentally unsound to make the earth road the basis of our economic study of highways. The basis should be a satisfactory all-year, all-weather road suitable for the motor car. Anything less than this is a social and economic loss.

We have further deluded ourselves by accepting as fundamental facts the two assumptions, first, that the costs of transportation are the primary considerations in road improvement, and, second, that highway improvements are financial investments. An ultimate analysis must lead to the inevitable conclusion that social and other intangible benefits constitute the real justification for improved highways, while reduced costs of transportation merely help to pay the bill. Furthermore, adequate highways are a *necessity of life* to the modern nation, and necessities are invariably expenses and not investments. An adequate plan of highway administration, an equitable scheme of highway financing, and a sound conception of highway economics will not be developed until alleged costs are pushed into the background, and highway service is brought to the front.

CHAPTER 2

NON-BITUMINOUS MATERIALS

Non-bituminous materials are those which do not contain bitumen as an essential element of their composition. The non-bituminous materials include earth or soils, sand, gravel, stone, brick, tile, cement, wood, metals, paint, etc.

EARTH

Earth is the loose, soft portion of the earth's crust in which plants grow and which normally forms mud when mixed with water. *Soil* is earth of any particular character or composition but the two terms are often used synonymously and interchangeably. All soils are the products of the decomposition of rocks. The nature of a soil therefore depends on the character of the parent rocks and also on the processes taking place during its formation.

Soil Properties.—Successful road building depends on the ability of the earth to support the loads placed upon it, to resist the destructive or erosive action of the elements, and, in some cases, to act as a binder to other materials. The presence or absence of certain properties controls the behavior of the soil. The more important of these *properties* are cohesion, internal friction, capillarity, permeability, porosity, stability, compressibility, elasticity, and volume change. These terms are reasonably descriptive in their ordinary meaning, but for their exact technical definitions and their interpretations as related to subgrade soils the reader is referred to *Reports on Subgrade Soil Studies*[1] of the U.S. Department of Agriculture.

Effect of Moisture.—All soils change character with changes in moisture content. With some soils this change is comparatively small over a considerable range of moisture content. With other soils only a small change in the moisture may result in a large change in character. This behavior of soils is of great importance

[1] Reprinted from *Public Roads*, Vol. 12, Nos. 4, 5, 7, and 8, 1931. Superintendent of Documents, Washington, D. C.

in road building. Arbitrary tests have therefore been devised to find the limits of these changes.

The *shrinkage limit* is the moisture content below which the sample does not shrink but above which it expands. The *centrifuge moisture equivalent* is the moisture content retained after a saturated sample is centrifuged for one hour with a force of

TABLE 2-1.—TYPICAL SOIL CONSTITUENTS (*U. S. Bureau of Public Roads*)

Name[1]	Maximum size, millimeters	Minimum size, millimeters	Properties
Gravel	6.0* (0.25 in.)	2.0 (No. 10 sieve)	Adds internal friction. Reduces shrinkage
Coarse sand	2.0 (No. 10 sieve)	0.25 (No. 60 sieve)	Same as above
Fine sand	0.25	0.05	Inert
Silt	0.05	0.005	Adds to capillarity
Cohesive clay	0.005	....	Provides cohesion. Provides plasticity. Causes shrinkage
Colloidal clay	0.001	....	Adds to cohesion, plasticity, and shrinkage
Mica flakes	....	....	Reduces stability and shrinkage
Diatoms	....	....	Add to capillarity
Peat	....	....	Adds to fluidity. Reduces stability
Humus	....	....	Modifies capillarity. Modifies plasticity. Holds moisture. Adds to fertility
Chemicals	....	....	Some flocculate colloids. Some deflocculate colloids
Miscellaneous	....	....	Cause acidity, color, etc.

[1] It is unfortunate that the same names are applied to soil constituents, soil textures, and soil types. Care is necessary to avoid ambiguity or confusion.

* Not given by soil analysts. Made to conform to the usual engineering limit for fine aggregates.

1,000 times gravity. If free water remains on top of the centrifuged samples, it is said to be *water-logged*. The *field moisture equivalent* is the minimum moisture content at which a drop of water placed on a sample with a smooth surface will spread out and give a shiny appearance. The *effective size* is the maximum size of the smallest 10 percent by weight of the soil particles.

The *liquid limit* is the highest moisture content at which the soil will just begin to flow when a standard specimen is jarred in a specified manner (see report referred to in the preceding paragraph). It indicates the point at which the soil tends to become fluid. The *plastic limit* is the lowest moisture content at which the soil can be rolled into threads 1/8 in. in diameter without the threads breaking. It indicates the change from a plastic to a crumbly condition. The *plasticity index* is the difference between the liquid limit and the plastic limit. It therefore indicates the range of moisture content over which the soil remains plastic. A high plasticity index indicates small changes of character with moisture changes. The plasticity index aids in forecasting the behavior of soils in subgrades and is valuable in choosing soils for binders in sand-clay roads and in the construction and stabilization of gravel roads.

Constituents.—The properties and character of soils are affected by the size and gradation of the rock particles and the presence of other materials. Table 2-1 gives the common constituents of many soils.

Texture.—Texture indicates the size of particles and the proportion of the different sizes present. In the laboratory it is determined quantitatively by mechanical analysis. In the field it is estimated qualitatively by the "feel," as smooth, fine grained, gritty, etc., and by its behavior in handling. Table 2-2 gives the more common soil textures.

Structure.—Structure indicates the general arrangement of the particles or groups of particles composing the soil. The structure is indicated by descriptive terms such as cloddy, laminated, formless, columnar.

Classification.—The U. S. Bureau of Public Roads has classified subgrade soils into eight groups based on laboratory tests and the behavior of the soils in the subgrade.[1] The characteristics of these groups are summarized in Table 2-3. By comparing the test results on an unknown soil with those in the table it is possible to estimate its probable behavior.

Soil Types.—Common usage has divided the soils into a number of types which are generally recognized although each may show wide variation in characteristics.

Clay.—The clays are fine grained, dense, and tough. They consist essentially of kaolin mixed with finely divided quartz,

[1] See *Soil Studies Report* previously mentioned.

feldspar, mica, etc. The color varies through nearly all shades owing to impurities. The *plastic* clays absorb and give up water with difficulty and have a high plasticity index. Their muds can be molded into shapes which become hard when dry and which break down slowly when immersed. These clays do not erode easily and are underdrained with difficulty. They are rather difficult to excavate and compact, but work best when

TABLE 2-2.—SOIL TEXTURES (*U. S. Bureau of Public Roads*)

Name	Principal constituents, percent by weight				Characteristics
	Clay	Clay and silt	Silt	Sand and coarse particles	
Sand	....	Under 20	....	Over 80	Will not form dry cast.[1] Moist cast crumbles
Sandy loam	Under 15	20 to 50	....	50 to 80	Dry cast crumbles. Moist cast fragile
Loam	Under 20	Over 50	Under 50	Under 50	Mellow, smooth, plastic. Dry cast fragile. Moist cast firm
Silt loam	Under 20	Over 50	Over 50	Under 50	Cloddy—clods fragile. Dust has floury feel. Dry and moist casts firm. Runs together when wet
Clay loam	20 to 30	Over 50	Under 50	Under 50	Moist soil plastic. Kneads into compact mass. Will not ribbon.[2] Dry clods hard
Clay	Over 30	Over 50	....	Under 50	Plastic—easily kneaded. Forms long ribbons

[1] Cast made by squeezing a handful.
[2] Ribbons formed by squeezing between thumb and finger.

slightly moist. They are excellent binders for sand-clay and gravel roads. Clays used in the manufacture of brick, tile, and pottery belong to this type. The *slaking clays* have a low plasticity index. They absorb water quickly and consequently change into mud readily but may dry out rapidly. They are easily worked but do not form good binders. *Fire clay* is capable of resisting high temperatures without fusing and is used in the manufacture of refractories.

Shale.—The shales are indurated clays. They are rock-like in character but vary much in hardness. When exposed to air and moisture they disintegrate into mud. They can usually be

TABLE 2-3.—CLASSIFICATION OF SUBGRADE SOILS (*U. S. Bureau of Public Roads*)

Group	Character	Properties	Gradation	Liquid limit	Plasticity index	Centrifuge moisture equivalent	Field moisture equivalent	Shrinkage limit
A1	Well graded—good binder. High stability irrespective of moisture conditions	High cohesion and internal friction. Negligible expansion, shrinkage, capillarity, or elasticity	Clay 5 to 10 percent. Silt 10 to 20 percent. Sand 70 to 85 percent. Coarse material 10 percent. Effective size 0.01 ± mm.	14 to 25	8 or less	15 or less	Not significant	14 to 20
A2	Not well graded—poor binder. Loose and dusty when dry. Stable when moist. Soft when wet	High cohesion and internal friction with moderate moisture. Expansion, shrinkage, capillarity, and elasticity sometimes detrimental	More than 55 percent sand	14 to 35	15 or less	25 or less	Not significant	Not important
A3	Coarse material only—no binder. Low stability under loads (when dry). Unaffected by moisture. Good support for pavements	High internal friction. No cohesion. Negligible expansion, shrinkage, capillarity, and elasticity	More than 70 percent sand. Effective size 0.10+ mm.	10 to 35	None	12 or less	Not significant	None
A4	Silt without coarse material. No sticky clay. Absorbs water—loses stability. Frost heaves—fair support	Little cohesion. Internal friction variable. No elasticity. Troublesome capillarity and shrinkage	Less than 55 percent sand	20 to 40	24 or less	More than 12	When greater than CME indicates expansive soil	Usually less than 25
A5	Similar to A4 but poor support for gravel and macadam	Similar to A4 but with troublesome elasticity	Less than 55 percent sand	More than 35	24 or less	More than 12. Rarely water logs	Below 80 good binder. Above 80 elastic soil with mica or diatoms	Usually more than 30. Above 50 very objectionable
A6	Clay without coarse material. Absorbs water when manipulated and becomes fluid. High expansion and shrinkage	Low internal friction. High cohesion with low moisture. No elasticity. Troublesome expansion and shrinkage	More than 30 percent clay	More than 35	36 or less	More than 12. May water log above 40	Less than 80	Below 20
A7	Similar to A6 but with high elasticity. Poor base for gravel, macadam, or rigid pavements	Similar to A6 but with troublesome elasticity	More than 30 percent clay	More than 35	More than A5 but less than A6	More than 12. May water log above 90	Above 80	Above 20. High values indicate frost heave
A8	Very soft peat or muck. Low supporting power	Low internal friction and cohesion. Troublesome capillarity and elasticity. Very low stability	Not significant	More than 45	24 or less	More than 12	Similar to A5	Above 20

excavated with a power shovel but not with the elevating or blade grader. Sometimes they require blasting. Most varieties are not suitable for road surfaces and form poor binders. The shales form the principal raw material for paving brick and are also largely used in making building brick, tile, terra cotta, haydite, etc.

Silt.—Silt is eroded soil of any kind deposited by water. It is granular and porous and lacks both cohesion and internal friction. Its plasticity index is low and its stability poor. It is easily excavated and easily eroded. Underdrainage is easy, provided the soil is prevented from washing into the drain. Silts have low supporting power, do not form good subgrades or surfaces, and are poor binders.

Loam.—The loams are more or less granular and porous but contain enough clay to be moderately cohesive and plastic. Considerable humus may be present. They constitute the best agricultural soils. When slightly moist they work well under the plow and blade or elevating grader; hence in general they are easily excavated and handled. They form only fair surfaces and are only moderately good binders. Underdrainage is easy, but surface water may cause erosion. *Loess* is a peculiar fine-grained loam deposited by wind and water. It never gets very hard and is easily eroded but may stand in vertical banks. It is neither a good surfacing material nor a good binder.

Gumbo.—Gumbo is a dark-colored, very fine-grained, tough, and tenacious loam with a high clay content. Its cohesion is high as is its plasticity index. It forms a very sticky, gummy mud and for this reason gumbo roads often become impassable when saturated. It takes up water slowly and dries out slowly. When dry it is very hard and when moist may be rubbery, due to high elasticity. Underdrainage is almost impossible. Gumbo is one of the most difficult soils to handle. It forms a good binder when well mixed with sand or gravel.

Adobe.—Adobe is a soil somewhat similar to gumbo found in a number of the southwestern states. It is known especially for its use in making sun-dried brick and blocks much used for building purposes.

SAND

Sand is a hard granular material formed by the natural disruption or disintegration of rocks.

The size of particle varies from that which will be retained on a 200-mesh sieve to some maximum size, depending on the character of the work in which it is to be used. Soil definitions fix this maximum size at about $\frac{1}{16}$ in. (10-mesh) but engineering practice uses limits up to $\frac{1}{4}$ in. Owing to the mechanical methods of preparing, commercial sands carry a small percentage of material somewhat larger than the nominal maximum size.

Sand Soil.—Sand is classed as a soil when it forms the surface stratum of the ground. Sand soils generally contain more than 80 percent of sand mixed with clay, silt, or loam. When dry they are loose and shifting, but usually reasonably stable when wet. Sand is worthless as binder but is useful as aggregate in sand-clay construction. Sand drains quickly if there is an outlet, erodes easily, and is easily excavated.

Composition.—The composition of sand is variable, depending on the nature of the parent rocks, and the conditions under which it was formed and deposited. Usually siliceous materials predominate. A sand must be hard, tough, and durable to be of service in engineering works and this is a function of its composition. The composition is best determined by examination under a low-power magnifier for the identification of principal rocks present.

Occurrence.—Sand is widely distributed. It occurs in deposits of varying size and character depending on the condition of formation, transportation, and deposition. Usually sand is found mixed with pebbles and small boulders (gravel). The process of obtaining the sand for engineering work is combined with that of preparing gravel. Wind, water, and ice had much to do with the nature of sand deposits.

Residual Sands.—These sands occur usually in the talus slopes where formed. The grains are angular and usually they are not well graded. Soil resulting from the further disintegration of the rock or carried in by water may be mixed with the sand. Residual sands are not important commercially.

River Sand.—River sand is found in beds or bars in streams, usually intermixed with gravel but generally free from much clay or silt. The grains are ordinarily well rounded and graded in size with the softer materials largely absent. It is excavated by dipper, ladder, or suction dredges, which process usually further washes it, and then screened to separate the sand and gravel.

Lake and Sea Sands.—These two kinds of sand are similar to river sands. The latter may be objectionable on account of the residual salt. *Beach* sand is likely to be quite fine on account of wave action.

Bank Sand.—Sand which is found in deposits other than bars or beds in streams or bodies of water is known as bank sand. A great many such deposits are *glacial*, while others are due to changes in stream channels. Bank sands, especially of glacial origin, are usually mixed with gravel and more or less clay and silt and are frequently overlaid with a stratum of soil which must be removed. The material is excavated by drag line or shovel and then screened to separate the sand from the gravel and washed to remove the dirt. Such sands are often called *washed sands.*

Dune Sand.—Dune sand is found in hillocks or dunes which have been formed by wind action. Such sands are hard, siliceous, and clean but usually are also extremely fine and hence of little value in highway construction.

Weight.—(See A.S.T.M. C29-27.[1]) Sand is sold by the cubic yard or the ton but is always shipped by weight. Various sands weigh from 95 to 115 lb. per cubic foot depending on the composition and the gradation. This is equivalent to about 2,650 to 3,100 lb. per cubic yard. Well-graded glacial and river sands in the Mississippi Valley weigh 2,800 lb. or more and are usually shipped as 3,000 lb. to the cubic yard, which is the legal weight in some states.

Sharpness.—It is often specified that sand shall be *sharp.* This usually means that the grains shall be angular rather than rounded. In making concrete, this point is of little importance, provided the grains have an unpolished surface to which the cement can adhere. Angular grains of silica are likely to be newly broken and expose glassy surfaces to which cement of any kind will not readily adhere, whereas rounded grains of the same kind will show surfaces like ground glass, to which cement will stick. This condition can be observed with a magnifier. Angular grains cause greater internal friction; hence mortar or concrete containing them requires more work and slightly more water to

[1] American Society for Testing Materials serial designation of the standard test. The letter and number indicate the society committee having jurisdiction. The last two numbers indicate the year of adoption of the standard. *T* indicates a tentative standard.

compact well. This greater resistance to displacement is desirable in bituminous mixtures.

Gradation.—Sands which have grains graded in size are preferred in all engineering work since they possess fewer voids to be filled with binder and possess greater internal friction, especially when angular. Fortunately the gradation may vary over a considerable range without marked difference in the behavior of the sands so that specifications can be made fairly simple and yet sufficiently adequate.

Cleanness.—Nearly all sands carry some clay or silt mixed with or adhering to the grains. Such clay or silt is objectionable in most work and the amount is therefore limited by specification. For high-grade concrete work the amount is restricted to about 2 percent by weight, while up to 8 percent is permitted in some other kinds of work. Sand for use in sand-clay or gravel roads may contain as much as 25 percent of clay.

Tests.—Sand is tested for *strength* (A.S.T.M. C87-36) by being formed into test specimens with portland cement. *Soundness* is defined as the ability to resist the disintegrating action of the elements and is determined from a knowledge of the component rocks or by accelerated tests (A.S.T.M. C88-35). *Gradation* (A.S.T.M. C41-33, D7-27) is found by a sieve analysis and *cleanness* by washing and sedimentation, termed *elutriation* (A.S.T.M. D136-28).

The *fineness modulus* is sometimes used to indicate the gradation of a sand. This factor is found by adding together the total percentages retained on sieves 4, 8, 14, 28, 48, and 100 of the Tyler series and dividing by 100. Practically the same value can be obtained by using U.S. Standard sieves 4, 10, 20, 30, 50, and 100. A good concrete sand should have a fineness modulus of not less than 3.0, while plastering and mortar sands may have a value as low as 2.0.

GRAVELS

Gravel is a natural material consisting of small, more or less rounded stones or pebbles.

From an engineering standpoint, gravel includes only the particles larger than sand and smaller than boulders, or generally smaller than about 3 in. in diameter. The term, however, is also applied to mixtures of pebbles, sand, and perhaps soil. Gravel occurs in natural deposits, as does sand, the two usually being

mixed together. The processes of excavation, screening, and washing are therefore common to the two.

Bank-run or Pit-run Gravel.—This class of gravel is the mixture of soil, sand, and pebbles as it occurs in nature. It is used for road surfacing, for railroad ballast, and to a limited extent in concrete.

Screened Gravel.—The material separated from the sand by screening is known as screened gravel. It may be screened to any desired size. Screened gravel when used alone is not suitable for road surfacing since it contains no binder. It is

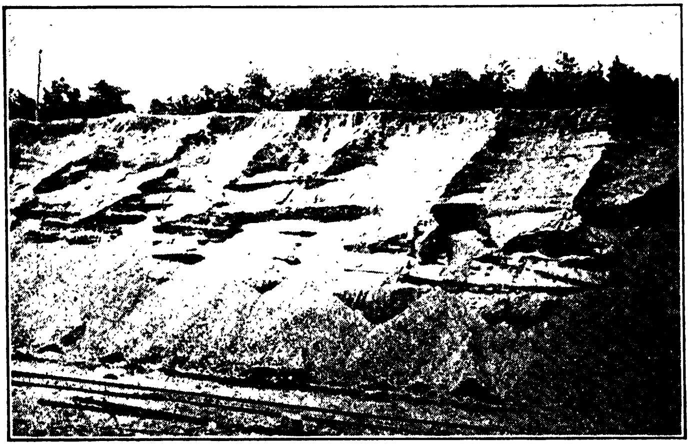

FIG. 2-1.—A glacial gravel pit.

sometimes used for railroad ballast but is primarily prepared for concrete aggregate. *Washed gravel* is material that is washed in its preparation. Washing and screening almost always go together.

Crushed Gravel.—Gravel in which the amount of coarse material has been increased to at least 10 percent of the whole by crushing the smaller boulders contained in the natural deposit is known as crushed gravel.

Concrete Mix.—This is a washed gravel from which part of the sand has been screened. The proportions of sand and pebbles are variable and rarely correct but the material may be used satisfactorily on small work for the sake of economy.

Pea Gravel.—Pea gravel is screened gravel between $\frac{1}{4}$ and $\frac{1}{2}$ in., or sometimes $\frac{3}{4}$ in., in size. It may be specifically prepared but is often a byproduct at gravel plants owing to the requirements

of specifications for concrete aggregates. It is an excellent surface dressing for gravel roads and as a cover material for surface treatments with bituminous materials. It is sometimes called *roofing gravel* since it is much used in composition roofs.

Weight.—Gravel, like sand, is sold by the cubic yard or the ton but is shipped by weight. Bank-run gravel, because of low voids, is heavy and will frequently exceed 3,000 lb. per cubic yard. Screened gravels will weigh from 2,700 to 3,100 lb. depending on the uniformity of size to which screened (A.S.T.M. C29-27). All such gravels usually ship at 3,000 lb. per cubic yard which is the legal weight in some states. The usual carload is 30 to 40 cu. yd.

Composition.—The composition of gravel is similar to sand. Because it is less finely pulverized, soft materials are more likely to persist and gravels must be examined for such rocks as may be considered objectionable. To make this examination, a typical sample weighing 1 to 2 kg. is spread on a table and the objectionable materials picked out, weighed, and the percentage determined. For pavement work such material should be practically entirely absent. Pavement bases and structures may admit 3 to 5 percent by weight. Sandstone, ochre, slate, and shale are the most common but other objectionable materials sometimes occur. Not more than 1.0 to 2.0 percent of such material should be permitted in aggregate for concrete pavements but 6.0 percent may be permitted in ordinary concrete. In some gravels a variety of limestone is found which expands on freezing. It often damages concrete work when near the surface by expanding and breaking out conical pits. The same material is also present in the accompanying sands but in smaller particles. It is decidedly objectionable, and aggregates containing it should not be used in concrete.

Gradation.—Gravel should be well graded from fine to coarse. This is determined by a sieve analysis (A.S.T.M. C41-36). The sieve-analysis curve for a high-grade gravel should approximate a straight line.

The fineness modulus is also used for gravel but the complete set of sieves are 1½, ¾, and ⅜ in. and Nos. 4, 8, 14, 28, 48, and 100. A well-graded gravel from ¼- to 1½-in. size should have a fineness modulus of not less than 5.75.

Soundness.—Soundness for gravel, as for sand, may be defined as the ability to withstand climatic forces. This can be deter-

mined only by the test of service but may be approximated by freezing tests, by repeated treatments with sodium sulphate (as for crushed stone), or by studying the composition. Durability is imperative in gravel roads and in concrete (A.S.T.M. C89-35).

Wearing Quality.—Gravel road material must possess ability to resist abrasion. No very satisfactory method of testing this quality has been devised owing to the variation in composition and gradation. The Deval abrasion test for stone, somewhat modified, is sometimes used (see A.S.T.M. D289-28T). The results are not exactly comparable with the stone test.

Binding Quality.—A road gravel must have the property of consolidating or packing. This is partly a function of composition and gradation but it depends mostly on the presence of a binder. Bank-run gravel is often used because it contains sand to fill the voids and clay as a binder.

STONE

Stone is rock material artificially reduced to pieces of such size as to be useful in engineering work.

Rock refers specifically to large natural masses of stone material and *stone* to the usable fragments, but the terms are often used synonymously.

Rock Classification.—Rocks are broadly classified as igneous, sedimentary, and metamorphic.

Igneous Rocks.—Igneous rocks are produced by the action of intense heat. They are generally hard and tough, granular in composition, and exhibit very little or no bedding. Granite and basalt are examples.

Sedimentary Rocks.—Those rocks resulting from the consolidation of sediment deposited from water are known as sedimentary rocks. They show a decided tendency to form layers or beds. Limestone and sandstone are sedimentary rocks.

Metamorphic Rocks.—Either igneous or sedimentary rocks which have been modified in structure and character by the action of heat, pressure, and movement are metamorphic rocks. Thus marble is metamorphic limestone and gneiss is metamorphic granite.

Granite.—The granites constitute a group of crystalline granular, igneous rock consisting principally of quartz and feldspar. They are hard, tough, and durable and can be given a high

polish. The color is usually gray or pinkish but may be red or black. Although without distinct bedding planes, the granites are readily cut or broken to regular shapes. They ordinarily crush to cubic rather than flaky fragments. They are valued as building stones and are also used for paving blocks, concrete aggregate, and sometimes in macadam.

Gneiss.—The gneisses are a group of granitic, metamorphic rocks. Due to the metamorphosis they possess planes of cleavage and split more readily than granites. They are often substituted for granite.

Trap.—Trap is a generic name for any dark-colored, fine-grained igneous rock. *Basalt* and *diabase* are the typical varieties. The traps are hard and tough and are not readily split to regular shape. They are, therefore, little used for building stone and paving blocks but are excellent concrete aggregates and the best of macadam road stones.

Limestone.—The limestones are sedimentary rocks composed essentially of calcium carbonate with impurities. Limestones vary from white through gray, blue, yellow, or red to nearly black. *Dolomite* is limestone containing considerable magnesium carbonate. The limestones vary in hardness but many are excellent for road and concrete work. All limestones show distinct bedding and they break readily to regular shape. Many make excellent building stones but are rarely used for paving blocks. The principal metamorphic limestone is marble. It is valued for building but is rarely used in road work. On heating limestone, $CaCO_3$, the carbon dioxide is driven off leaving calcium oxide, CaO, the *quicklime* of construction.

Sandstone.—Sandstones are sedimentary rock formed by the cementing together of sand by silica, iron oxide, or calcium carbonate. They vary in color from white to nearly black, red being very common. The sandstones vary in hardness. Some form excellent building stones, concrete aggregate, or paving block but none form good macadam stone owing to low toughness and cementing values. They are readily split to shape and some, when freshly quarried, are easily carved. Many, however, do not stand weathering.

Quarrying.—Quarrying is the artificial process of removing stone from its native rock for the use of man. Two general methods of quarrying are used. For building stone and similar use the stone is desired in regular shapes with little waste. The

rock is carefully drilled and channeled and blasted with light charges in such a manner as to break out regular-shaped blocks of suitable size which are later split as required and hauled to the cutting sheds.

For concrete aggregate, road stone, etc., the rock is required in smaller sizes without regard to shape. Heavy charges of explosive are used to shatter and throw down a large volume of stone of a size which may be loaded by steam shovel into cars for haulage to the crushing plant.

Cut Stone.—Stone which is split, trimmed, and tooled or polished for building purposes is known as cut stone.

FIG. 2-2.—A roadside stone quarry with temporary crushing and screening plant.

Paving Blocks.—Small stone blocks prepared expressly for paving purposes are called paving blocks. Granite and sandstone are generally used. Specifications require that the granite block shall be from 8 to 12 in. long, 3½ to 4½ in. wide, and 4½ to 5½ in. deep. Top irregularities shall not exceed ⅜ in. and the sides shall be so dressed that joints shall not exceed ½ in. for a depth of 1 in. or more than 1 in. anywhere. The stone shall show a percentage of wear between 7 and 14. Sandstone blocks are 8 to 12 in. long by 3 to 5½ in. wide by 6 to 7 in. deep and the joints should not be more than ½ in. for a depth of 2½ in. Small cubes about 3 in. in size are also frequently used.

Crushed Stone.—Crushed stone together with screened gravel forms the vast bulk of coarse aggregate for concrete. The stone

after being quarried is taken to a crusher and crushed to any desired maximum size. After crushing, it is screened to any desired size through a series of rotary screens, similar to those in a sand and gravel plant. Fragments larger than required are returned to the crusher. Washing may or may not be done, but water sprayed on the screens aids the screening and removes the dust from the particles.

Crusher-run Stone.—The crushed material as delivered by the crusher is known as crusher-run stone. It is sometimes used in concrete work, bituminous concrete, and broken stone roads consolidated by traffic.

Graded Stone.—Graded stone is graded between any desired sizes. Usually it begins at ¼ or ⅜ in. and ranges up to 1½, 2, or 2½ in.

One-size Stone.—The fraction retained between any two sieves differing only a little in size is known as one-size stone. They are usually designated by the larger size, thus "1-in. stone" ordinarily means stone ¾ to 1 in. Common sizes are ½ to ¾, ¾ to 1, 1 to 1½, 1½ to 2, and 2 to 2½ in. Sometimes for macadam roads of limestone 3- or even 4-in. stone is used.

Screenings.—The fine portion of the crushed stone screened from the prepared sizes is called screenings. Screening ranges from dust to ¼ in. or sometimes to ½ or ¾ in.

Stone Chips.—These are screened stone between ⅛ and ½ or ¾ in. in size. They may be regarded as screenings from which the dust has been removed. They correspond to pea gravel.

Stone Dust.—This is the material that will pass a 10-mesh sieve. For some work the stone is pulverized. Agricultural limestone usually passes a 100-mesh sieve and filler for asphaltic mixtures a 200-mesh sieve. Commercial stone dust generally carries some proportion of material larger than the specified size.

Qualities.—The requisite qualities of stone for use in highways are soundness, hardness, toughness, crushing strength, and cementing value. Some of these are combined in the so-called abrasion value.

Soundness.—Soundness is the ability to resist the action of the elements. Service, of course, will demonstrate this. Alternate freezing and thawing when saturated with water, or repeated saturation with a solution of sodium sulphate, and drying will indicate its probable durability (A.S.T.M. C89-35).

Hardness.—This is the ability to resist direct abrasion. It is tested by grinding a cylinder of the stone 25 mm. in diameter on a cast-iron disc rotated at 30 r.p.m. using crushed quartz as an abrasive. The loss in grams per 1,000 revolutions may be taken directly as the measure of hardness, or the quality may be expressed by the *coefficient of hardness,*

$$h = 20 - \frac{w}{3} \tag{2-1}$$

where h is the coefficient of hardness and w the loss in grams per 1,000 revolutions. A good limestone will show a value of h of 12 to 15, and granite and trap 15 to 19 (*U.S. Dept. Agr. Bull.* 1216).

Toughness.—This is the ability to resist impact. A cylinder 25 mm. in both length and diameter has the impact from a 2-kg. hammer transmitted to its end through a steel block with a spherical bearing. The blows start with a fall of 1 cm. and increase 1 cm. each blow. The number of blows which causes failure, which is also the height of the last blow in centimeters, is taken as the measure of toughness. Limestones usually range from 10 to 15, granite 15 to 20, and trap 20 to 40 (A.S.T.M. D3-18).

Abrasion.—Abrasion is a combined wear and impact test made by placing a washed and dried sample weighing 5,000 g. and consisting of 50 fragments in a cast-iron cylinder 20 by 34 cm. in dimensions, set at 30 deg. with a shaft, and rotated at 30 r.p.m. for 10,000 revolutions. The sample is again washed, dried, and weighed. The percentage loss of weight, called the *percent of wear,* is taken as the measure of the wearing qualities of the stone. The *French coefficient* of wear was formerly much used and is still frequently specified.

$$\text{F.C.} = \frac{40}{\text{percent of wear}} \tag{2-2}$$

A maximum percent of wear of 7 or a minimum F.C. of 6 is usually required for concrete aggregate and macadam stone.

This test (A.S.T.M. D2-33) is the one most commonly made for road purposes and usually replaces the hardness and toughness tests.

Cementing Value.—This value is of importance in macadam stone. It is tested by grinding the stone with distilled water in

a ball mill and molding the resulting paste into cylinders 25 by 25 mm. These are dried and then broken by the impact of a 1-kg. hammer falling 1 cm. The number of blows is the criterion. Sandstone shows little cementation, limestones 25 to 300, and trap 100 to 800. A minimum of 25 is usually required (*U.S. Dept. Agr. Bull.* 347).

Gradation.—Gradation is the same as for gravel and is made and used in the same way (A.S.T.M. C41-36).

Crushing Strength.—Tests for crushing strength are made on cubes or cylinders. This test is little used on road stone and only occasionally on building stone. A cylinder 2 in. in diameter by 4 in. long should give a value of at least 10,000 lb. per square inch on a stone having a percent of wear less than 7.

Specific gravity is useful in various calculations and as an aid in identification. The specific gravity of rock ranges from about 2.6 to about 2.9 (A.S.T.M. C86-31T, C127-36T, C128-36T).

BRICK

Brick are regularly shaped blocks of burned clay.

Soft brick are usually made of surface clay and burned at a low temperature. They are soft and porous.

Hard-burned brick are made of surface clay or shale and are burned at a higher temperature. They are harder and less porous than soft brick, often approaching the vitrified brick.

Vitrified brick are made of suitable shale or impure fire clay and burned at such a temperature that incipient fusion is reached so that the particles unite into a solid, partially vitrified mass.

Building brick are used in buildings and similar construction. They are usually about 2¼ by 4 by 8½ in. in size and may be soft, hard burned, or vitrified. *Face brick* are hard-burned or vitrified brick, selected for use in the exposed face of a wall. They are often specially scored or roughened for ornamental effect. *Common brick* are building brick other than face brick.

Paving brick are vitrified brick especially made for paving purposes. Culls are used as common brick.

Manufacture of Paving Brick.—The shale or fire clay is ground in a dry pan to pass about a ¼-in. to 20-mesh screen. It is then mixed with water in a pug mill to a very stiff plastic mud. This mud is then forced through a die in a continuous column which is cut off to desired size by means of taut wires. The clay shrinks about 20 percent in volume while drying so that the brick are

molded and cut oversize. The green brick are dried for a period of 2 to 4 days. Waste heat from the kilns is often used to aid the drying. The brick are stacked in the kiln so that the heat can circulate around and between them, fine quartz sand being used between layers to prevent sticking.

Firing is started at a low temperature so as to drive off the remaining free water and some of the combined water. This requires from 1 to 3 days. The heat is then gradually increased until all the organic matter is burned out. These stages are rather critical as too fast firing will cause the brick to swell and disrupt owing to the rapid formation of steam and carbon dioxide.

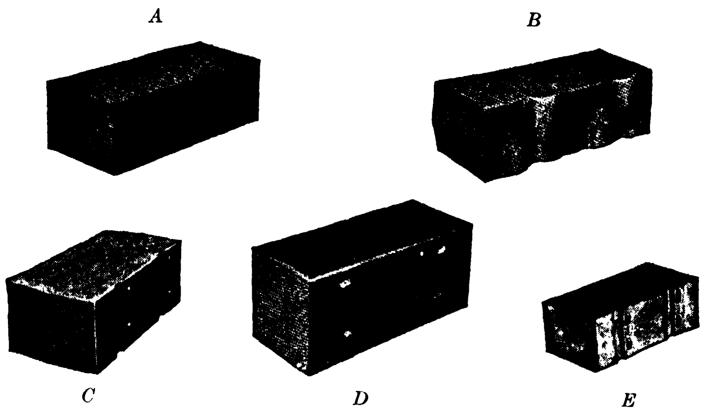

FIG. 2-3.—Types of paving brick. *A*, plain wire cut; *B*, wire cut lug; *C*, vertical fiber with beveled ends; *D*, repressed lug; *E*, vertical fiber with end lugs.

After the carbon is burned out, the temperature is raised to about 1400°C. and held there for 1 or 2 days to cause vitrification. The kiln is then slowly cooled to anneal the brick. This burning and annealing process requires 5 to 12 days, the entire process requiring 8 to 14 days. The kiln is then opened and the brick removed and sorted, usually into No. 1's, No. 2's, and culls.

Kinds.—Formerly there were a large number of varieties and sizes of paving brick but as the result of standardization there are now only two recognized varieties and three sizes as shown in Table 2-4. Occasionally unusual sizes or shapes are made for special purposes such as flangeways for streetcar tracks.

Plain wire-cut brick are made by cutting a rectangular column of clay with wires that move directly through it. Four faces are smooth from contact with the die, while the other two are rough owing to the cutting.

Wire-cut lug brick (Dunn patent) are made by guiding alternate cutting wires so as to form four slight elevations on one cut face of each brick to serve as spacing lugs. This type is by far the best for use with cement grout filler and is desirable for bituminous filler.

Repressed brick are subjected to heavy pressure in molds after cutting. The edges are usually rounded to a small radius and raised letters or lugs formed in one or more faces to aid in spacing.

Vertical-fiber brick are wire-cut brick placed in the pavement with a wire-cut face uppermost. The name is derived from the idea that a fibrous condition of the clay is developed in the die

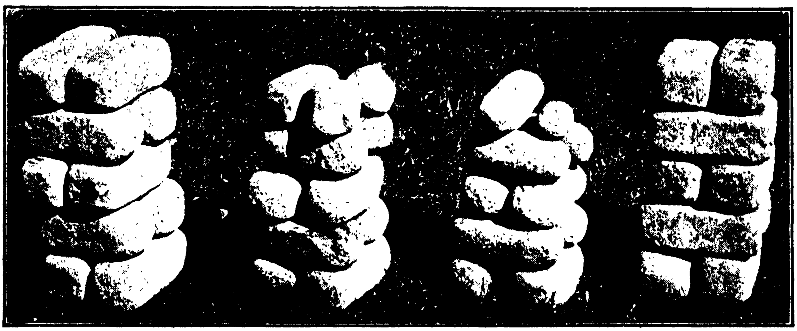

FIG. 2-4.—Brick after rattler test. These samples of brick of two different makes were taken from the same street after about 4½ years of service. The two middle piles tested 30.7 and 47.7 percent, respectively, and their section of the pavement was badly worn. The extreme piles tested 16.0 and 16.2 percent, and their section was in practically perfect condition.

machine and that these fibers are cut across by the wires and then placed so as to take the wear on the ends. This is analogous to the grain in wood blocks. That such fibers exist is extremely doubtful. The brick are, however, more uniform in thickness when laid in this way; hence a smoother pavement can be obtained. Vertical-fiber brick originally were plain wire cut but the need for uniform joints to permit the proper entry of the filler has led to the development of a lug type.

Deaired brick are made by performing the operations of mixing and forming under a fairly high vacuum. This results in a clay column that is denser and freer from laminations than that formed in the usual way. The resulting brick are harder, stronger, and more resistant to wear than the ordinary kind. These brick have not as yet (1935) come into general use but they are gaining in favor.

Qualities.—Paving brick must be durable, hard, tough, uniform in size and shape, and have low absorption of water. Experience and tests have demonstrated that well-burned brick have ample durability or resistance to the elements and also very low absorption. Size and shape can be determined by inspection and measurement. Hardness and toughness are measured by the rattler test.

Rattler Test.—Hardness and toughness are determined together in the standard rattler test (A.S.T.M. C7-30). For this test 10 brick are selected, dried, weighed, and placed in the rattler. The rattler barrel is made up of cast-iron-lined heads with 14 steel-lined staves. The inside dimensions are about 20 in long by 27 in. in diameter. The barrel is so mounted as to be driven at a speed of 30 r.p.m. An abrasive charge consisting of 10 spherical cast-iron shot weighing between 7 and 7½ lb. each, and enough similar shot between 1¾ and 1⅞ in. in diameter to make a total charge of 300 lb. is included with the brick. The barrel is revolved 1,800 revolutions for the test, requiring 1 hr. The brick are removed and weighed, and the percentage of loss determined.

The standard test calls only for the average loss of 10 brick. Frequently the brick are marked and individual records kept. Specifications then provide for the average loss of the 10 and also for the maximum loss of any individual brick. This tends to secure greater uniformity in quality. Another advantage is that by choosing the test brick to cover the range of color, or other characteristics of the brick, the inspector can obtain from

TABLE 2-4.—PROPERTIES OF PAVING BRICK

Variety	Dimensions			Approximate weight, pounds	Permissible rattler loss[1] (A.S.T.M.), percent
	Depth, inches	Width, inches	Length, inches		
Vertical fiber lug[2]	2½	4	8½	7	26
Vertical fiber lug[2]	3	4	8½	8½	24
Vertical fiber lug[2]	3½	4	8½	10	22
Repressed lug[2]	4	3½	8½	10	22
Wire cut lug	3	3½	8½	7	26
Wire cut lug	4	3½	8½	10	22

[1] Average of 10 brick. Individual brick should not exceed these values by more than 3.
[2] Recognized variety and size, U. S. Department of Commerce.

a single test information of service in the inspection and culling of the brick. Since uniformity in quality is of primary importance, it would seem that a minimum limit should also be provided but this is very rarely, if ever, done (see Table 2-4).

Cost.—The cost of paving brick at the plant varies with the cost of labor and auxiliary materials, especially fuel. Prices have risen considerably since the World War and often fluctuate. Number 1 pavers f.o.b. the plant ordinarily range from $33 to $36 per thousand for the smallest size and $40 to $45 for the largest size. Freight rates play an important part in the cost delivered on the job.

TILE

Tile are cylindrical pipe of concrete or burned clay used as conduits for carrying water.

Clay Tile.—Clay tile are made of either surface clay or shale. The process is quite similar to the manufacture of brick. The clay is worked into a stiff mud with water and then forced through

TABLE 2-5.—DIMENSIONS AND WEIGHTS OF DRAIN AND CULVERT PIPE

Internal diameter, inches	Area, square feet	Sewer pipe				Culvert pipe			
		Vitrified clay[1]		Reinforced concrete		Cast iron, Class B		Corrugated iron	
		Thickness, inches	Pounds per foot	Thickness, inches	Pounds per foot	Thickness inches	Pounds per foot	Gage	Pounds per foot
4	0.087	9/16	7½	...	...	0.45	21½		
6	0.196	5/8	13	...	...	0.48	33		
8	0.349	¾	20	...	...	0.51	47	16	7.2
10	0.545	7/8	30	...	...	0.57	64	16	8.9
12	0.785	1	43	2	88	0.62	82	14	12.9
15	1.227	1¼	70	2¼	121	....	...	14	15.7
18	1.767	1½	100	2½	164	0.75	150	14	18.8
21	2.405	1¾	135	...	...	....	...	12	30.6
24	3.142	2	175	3	264	0.89	233	12	34.3
27	3.976	2¼	215	...	...	....	...	12	38.5
30	4.909	2½	275	3½	378	1.03	333	12	42.7
33	5.939	2⅝	340	...	...	....	...	12	46.9
36	7.069	2¾	390	4	500	1.15	454	10	64.9
39	8.296	...	.....	...	...	....	...	10	70.2
42	9.621	...	.....	4½	655	1.28	592	10	75.4
45	11.045	...	.....	...	...	....	...	10	80.9
48	12.566	...	.....	5	870	1.42	750	10	86.4

[1] Size 4 to 12 in., inclusive, single strength, remainder double strength.

a die and cut to length, or else molded under pressure in forms to the desired shape. The green tile are dried in the air and then burned in kilns.

Common or Farm Tile.—Straight cylinders burned without vitrification or glazing are known as common, or farm, tile. They may be obtained in sizes from 4 to 36 in. in diameter, the lengths varying from 13 to 30 in. Since they are porous they will collect water throughout their entire length and therefore are suitable for underdrains.

Vitrified Tile.—Tile made of shale and burned to vitrification and usually glazed are called vitrified tile. They are stronger than common tile and therefore preferable when laid at considerable depth. Since they are non-porous they can collect ground water only through the joints. They are used as outlet tile for underdrains and for storm drains. The usual lengths are 24 and 30 in. Sizes up to 48, or sometimes 60, in. can be obtained.

Sewer Pipe.—Sewer pipe, often called *vitrified clay sewer pipe*, are vitrified tile made with a bell or hub on one end so that each tile slips into the preceding 2 or 3 inches. The bell serves to hold the tile in line and prevents the soil from washing at the joint. The joint may be sealed by calking with oakum, cement mortar, or bituminous joint fillers to prevent infiltration or exfiltration and to exclude tree roots, etc. The sizes and length are the same as ordinary vitrified tile. Sewer pipe are used for sanitary sewers, for storm drains in city work, and occasionally on rural roads.

Cement Tile.—Cement tile are made of portland cement concrete using a comparatively small coarse aggregate. The proportions are about 1:2:3. They may be dry molded or plastic molded. The dry-molded type is made by tamping a concrete of brown sugar consistency into molds, stripping the molds immediately, and then curing the tile with necessary moisture. They have a granular surface and are rather porous and hence are suitable for underdrains. The plastic molded type uses a concrete of plastic consistency and therefore must remain in the forms until set. They are less porous and have a harder surface than dry-molded tile and are therefore more suitable for sanitary sewers and storm drains.

When well made and properly cured, cement tile have a strength comparable with the clay tile. They are made in the same sizes and lengths. They may be plain cylindrical, of the sewer-pipe

type, or made with inside and outside tapers at opposite ends so that each tile will slip a short way into the preceding tile.

Clay tile are usually more economical in sizes up to 24 in., and also between 24 and 42 in. if there are no specials such as T's or Y's. With such specials the concrete tile is usually cheaper above 24 in. because of a cheaper way of making these junctions.

The price of both clay and cement tile varies considerably from time to time and place to place as well as with size. Local quotations should be secured for each project.

LIME

Quicklime.—Quicklime is obtained by burning limestone in which process the carbon dioxide is driven from the calcium carbonate, $CaCO_3$, leaving calcium oxide, CaO. Quicklime slakes, by the addition of water, into calcium hydroxide, which, with an excess of water, forms the lime paste used in making mortar. The slaking generates considerable heat and care must be taken in storing lime, since the leakage of a small amount of water into it may develop enough local heat to cause a fire. Lime mortar sets by absorbing carbon dioxide, thus returning the oxide to the carbonate. It must therefore dry out and also be exposed to the air. It will not set in water. The usual proportions are 1 part lime paste to $2\frac{1}{2}$ to 3 parts sand.

Lime is shipped in wooden barrels of 180 or 280 lb., net, or in bulk. The 1934 price was about $1.25 for the smaller barrel, or $10 per ton in bulk, at the kiln.

Hydrated Lime.—By slaking without an excess of water, hydrated lime, or simply *hydrate*, is formed. This is a dry white powder and is usually shipped in paper bags of 50 lb., net. The price at the plant varies from $10 to $12 per ton in carload lots. Hydrated lime is used in mortars the same as lime paste, as a fertilizer, as a water softener, and in concrete. It also makes an excellent filler for bituminous pavement mixtures. Several different grades suitable for different classes of work are on the market.

The use of hydrate in concrete tends to increase the density, make the consistency more uniform, reduce the water required to give a desired workability, and, if not used in excess of about 5 percent by weight of cement, does not reduce the strength. Its use, therefore, may, in certain instances, carry advantages sufficient to justify the cost.

Hydrate may be used as a soil stabilizer for earth roads or subgrades. The lime tends to flocculate the colloidal clay, thus increasing the granularity and decreasing the plasticity; and certain soils seem to respond to the treatment. The best results are obtained on clays and clay loams with about 5 to 7 percent of hydrate by volume for a depth of about 6 in. It is applied by plowing and discing the soil, spreading the lime, discing it in, and then shaping with a blade grader.

Calcium Chloride.—Commercial calcium chloride consists of about 75 percent pure $CaCl_2$ mixed with small amounts of other salts, inert material, and water. It is highly hygroscopic and deliquescent, but this action is slowed in the commercial grade by the impurities. This is an advantage and aids in its storage. The 1934 price varied from $18 to $20 per ton at the plant.

Calcium chloride is used in highway work as an accelerator in concrete, for curing concrete, and as a dust preventive on gravel and macadam. An admixture of 2 percent of the weight of cement by dissolving in the mixing water acts as an accelerator and antifreeze compound for concrete.

For curing concrete pavements the dry material is spread uniformly over the surface at a rate of 2 to 2½ lb. per square yard. By absorbing moisture from the concrete and the air, it dissolves and completely covers the surface.

As a dust preventive it is spread on the surface where its hygroscopic action retains enough moisture to keep the binder in the gravel or stone in good condition and thus hold down the dust. It does not work well in either very dry or very moist climates. Usually about 1½ lb. per square yard is applied early in the summer season with a later application of ½ to 1 lb. if necessary. It is used in about the same amount to control the moisture and aid in stabilizing clay binder in stabilized gravel roads.

CEMENT

Portland cement is an artificial hydraulic cement. It is the principal cement of importance to the highway engineer. *Natural cement*, a hydraulic cement of lower strength, is little used at present. Cement differs from lime in that it requires water for setting and hardening and consequently it sets when immersed.

Manufacture.—Portland cement is made by grinding clay and lime (or equivalent) in the proportions of about 1:3 into an inti-

mate mixture. This powder is then burned at a temperature of about 1400°C. until a hard clinker is formed. This clinker is allowed to stand for several days to permit the uncombined lime to slake and then ground to a fine powder and allowed to cure further. It is then ready for use.

Shipping.—Cement was formerly shipped in wooden barrels containing 376 lb., net. It is now shipped in cloth or paper bags containing one-fourth of a barrel, or 94 lb., net, or in bulk for domestic use on large jobs. For export it is barreled as formerly. The bags of 94 lb. form a convenient unit of measurement. When well compacted a bag is equivalent to 0.95 cu. ft. and is often so used but in most work a bag is considered as 1 cu. ft.

Price.—Cement is quoted by the barrel and the price fluctuates. The 1934 mill price was about $1.60, net, after commissions and the surcharge of 10 cts. each for cloth bags were deducted.

Qualities.—Cement must set properly, gain sufficient strength, and retain its volume, shape, and strength indefinitely. (A.S.T.M. C9-30, C77-32.)

The *time of set* must be sufficiently rapid but must also allow sufficient time for the materials to be properly mixed and placed. *Initial set* is taken to be when a pat of neat cement paste ½ in. thick will just support a weight of ¼ lb. supported on a point $\frac{1}{12}$ in. in diameter. This must not take place in less than 1 hr. at normal temperatures. All work of mixing, placing, and finishing must be done inside this limit. *Final set* is when a weight of 1 lb. is just supported on a $\frac{1}{24}$-in. point. This should be reached in less than 10 hr. The cement then continues to gain in strength, rapidly at first, then more and more slowly, for an indefinite time.

Strength is tested by making suitable test specimens and breaking them. Tensile tests have become standard but compression and cross-bending tests have certain advantages and their use is increasing. The standard tensile tests are made on a 1:3 mortar, by weight, using Ottawa standard sand. The tensile strength must be not less than 275 lb. per square inch at 7 days and 350 lb. at 28 days, for standard portland cement.

The cement must be *sound* or capable of retaining its strength and volume indefinitely. This is tested by making, on a glass plate, a pat about 3 in. in diameter and ½ in. thick at the center with feather edges. After setting for 24 hr. this pat is subjected to a steam bath for 5 hr. at the end of which it must show no cracking, curling, discoloration, or disintegration.

The behavior of a cement depends somewhat on its *fineness*, which is determined by sifting. Not less than 78 percent must pass a 200-mesh sieve. Most commercial cements exceed this by a safe margin. The *specific gravity* of the cement particles is useful in certain calculations and also as a check against adulteration. It should be not less than 3.10 and rarely exceeds 3.25. The bulk specific gravity is about 1.5.

High Early Strength Cements.—High early strength cements have developed considerably since 1925. Most of them are modified portlands which will gain the same strength in ¼ to ½ the time of standard portlands. The cost of this type is only about 50 cts. per barrel more than standard cement. Consequently these cements are gaining favor for making repairs and on construction where the work must be put into service at an early age. The high-alumina cements are still faster in action but owing to much higher cost and certain objectionable characteristics they are little used in road work (A.S.T.M. C74-36).

METALS

Cast Iron.—Cast iron is used in highway work primarily for inlets, manhole cover, pipe, etc. Only the best gray iron, free from admixtures, should be used. The castings should be smooth, well formed, and free from sand blisters and blow holes. Cast iron is rather brittle but resists rust well. Bars in gratings over which wheels pass should be at least ¾ in. wide and 1½ in. deep, and deeper if the span is more than 12 in. Other castings should be not less than ½ in. thick. Gray-iron highway castings usually sell for 5 to 6 cts. per pound at the foundry.

Malleable Iron.—Thin cast iron that has been heat treated is known as malleable iron.

Steel.—The character and qualities of different steels are treated in books on the mechanics of materials and need not be given here.

Reinforcing Bars.—The reinforcing bars should be of medium steel, well rolled and free from rust and scale. Either round or square bars may be used. *Deformed bars* should be used where high bond is necessary and the length is limited, and especially where they cross an open joint. *Plain bars* must be used where the bond is to be broken by greasing or otherwise. For pavement reinforcement no bar smaller than ½ in. should be used

except when formed into mats or mesh, on account of the effect of corrosion at cracks and joints.

TABLE 2-6.—WEIGHTS AND AREAS OF STEEL BARS

Shape	Size, inches	Area, square inches	Weight per foot, pounds	Perimeter, inches	Surface area per foot, square inches
Round	3/8*	0.1104	0.376	1.1781	14.137
	1/2*	0.1963	0.668	1.5708	18.850
	5/8*	0.3068	1.043	1.9635	23.562
	3/4*	0.4418	1.502	2.3562	28.274
	7/8*	0.6013	2.044	2.7489	32.987
	1*	0.7854	2.670	3.1416	37.699
	1 1/8	0.9940	3.380	3.5343	42.412
	1 1/4	1.2272	4.172	3.9270	47.124
Square	3/8	0.1406	0.478	1.500	18.00
	1/2*	0.2500	0.850	2.000	24.00
	5/8	0.3906	1.328	2.500	30.00
	3/4	0.5625	1.913	3.000	36.00
	7/8	0.7656	2.603	3.500	42.00
	1*	1.0000	3.400	4.000	48.00
	1 1/8*	1.2656	4.303	4.500	54.00
	1 1/4*	1.5625	5.313	5.000	60.00

* Standard sizes for concrete reinforcement.

Mesh Reinforcing.—Wires or rods variously bonded together form mesh reinforcing. According to tests by the U. S. Bureau of Public Roads, small bars closely spaced are more effective than larger bars farther apart. The best spacing seems to be 4 to 8 in. Mesh reinforcing weighs from 3 to 10 lb. per sq. yd. and costs 3 to 5 cts. per pound in place. Various widths are obtainable but about 72 in. seems the easiest to handle. Formerly, mesh was shipped only in rolls and cut on the job. At present it can be obtained cut to length at the factory and shipped flat which is a great advantage, especially with the heavier styles.

Sheet Steel.—Sheet steel is used principally as center joints, spacing plates, culvert pipes, etc. It may be obtained plain, painted, or galvanized as required. Sheet steel is designated by its gage.

Wire.—Wire is used as an auxiliary in highway work as bar ties, form ties, anchors, etc. Usually iron or steel is used, either plain or galvanized. Wire is designated by its gage. Annealed

wire should be used for ties, etc., and hard wire where strength is required.

TABLE 2-7.—GAGES OF WIRE AND METAL SHEETS

Gage number	Wire						Sheets	
	American or B. & S. (all metals except steel)			American steel wire			U. S. Standard (black)[2]	
	Diameter, inches	Area, square inches	Pounds per foot (iron)[1]	Diameter, inches	Area, square inches	Pounds per foot (steel)	Thickness, inches	Pounds per square foot (iron)[1]
0000	0.460	0.16620	0.5614	0.3938	0.1218	0.4155	0.4062	16.250
000	0.410	0.13203	0.4456	0.3625	0.10321	0.3458	0.3750	15.000
00	0.3648	0.10450	0.3530	0.3310	0.08605	0.2936	0.3437	13.750
0	0.3249	0.08289	0.2800	0.3065	0.07378	0.2517	0.3125	12.500
2	0.2576	0.05213	0.1760	0.2625	0.05412	0.1845	0.2656	10.625
4	0.2043	0.03278	0.1110	0.2253	0.03987	0.1363	0.2344	9.375
6	0.1620	0.02062	0.0696	0.1920	0.02895	0.0987	0.2031	8.125
8	0.1285	0.01297	0.0438	0.1620	0.02062	0.0703	0.1719	6.875
10	0.1019	0.008155	0.0275	0.1350	0.01431	0.0487	0.1406	5.625
12	0.0808	0.005129	0.0173	0.1055	0.008742	0.0297	0.1094	4.375
14	0.0641	0.003225	0.0109	0.0800	0.005027	0.01716	0.0781	3.125
16	0.0508	0.002028	0.00684	0.0625	0.003068	0.01048	0.0625	2.500
18	0.0403	0.001276	0.00430	0.0475	0.001772	0.00603	0.0500	2.000
20	0.0320	0.0008023	0.00271	0.0348	0.0009511	0.00324	0.0375	1.500
22	0.0253	0.0005046	0.00170	0.0286	0.0006424	0.00219	0.0312	1.250
24	0.0201	0.0003173	0.00107	0.0230	0.0004155	0.00141	0.0250	1.000
26	0.0159	0.0001996	0.00067	0.0181	0.0002545	0.00086	0.0187	0.750
28	0.0126	0.0001255	0.00042	0.0162	0.0002061	0.00070	0.0156	0.625
30	0.0100	0.0000785	0.00027	0.0140	0.0001539	0.00053	0.0125	0.500

[1] For other metals multiply by: brass 1.06, copper 1.13, lead 1.46, zinc 0.93.
[2] For standard galvanized sheets add 0.16 lb. per square foot.

Ingot Iron.—Ingot iron is nearly pure iron similar to wrought iron used principally in culvert pipes as it resists rust better than steel.

METAL PIPE

Gas Pipe.—Ordinary steel gas or water pipe either plain or galvanized is little used in road work except for minor purposes. Its cost and tendency to corrode make it unsuitable for use in drainage work.

Corrugated Metal Pipe.—This type of pipe is quite useful in drainage work for culverts, etc. When well made of ingot iron galvanized both before and after being formed into pipe, it

resists corrosion to a high degree. Its relatively light weight makes it suitable for locations where hauling of materials is a problem. It is especially suitable for farm entrances and on secondary roads where costs must be kept down. Its use is questionable on high-class construction where greater expenditure is justifiable. The legitimate use of this pipe has been retarded by the sale of steel pipe of light weight and not well galvanized, which rapidly rusted out.

Cast-iron Pipe.—Cast-iron pipe was formerly much used for culverts, especially by the railroads. It is little used for this purpose now owing primarily to its high cost as compared with corrugated-metal and concrete culverts. It is much used for water mains and frequently employed in sewer work. Where a drain or sewer is carried through a manhole of another line above grade, or where a trench or other soft ground must be crossed, cast-iron pipe is highly desirable (see Chap. 5).

TABLE 2-8.—STYLES OF WELDED WIRE FABRIC
(Uniform-gage type)

Spacing of wires, inches		Size of wires (W & M gage)		Sectional area, square inches per foot		Weight, pounds	
Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	Per 100 square feet	Per square yard
6	6	0	0	0.148	0.148	107	9.6
6	6	1	1	0.126	0.126	91	8.2
6	6	2	2	0.108	0.108	78	7.0
6	6	3	3	0.093	0.093	68	6.1
6	6	4	4	0.080	0.080	58	5.2
6	6	5	5	0.067	0.067	49	4.4
6	6	6	6	0.058	0.058	42	3.8
6	12	0	0	0.148	0.074	81	7.3
6	12	1	1	0.126	0.063	69	6.2
6	12	2	2	0.108	0.054	59	5.3
6	12	3	3	0.093	0.047	51	4.6
6	12	4	4	0.080	0.040	44	4.0
6	12	5	5	0.067	0.034	37	3.4
6	12	6	6	0.058	0.029	32	2.9

Weights based on fabric 60 in. wide

NOTE: In addition to the foregoing there may be furnished numerous other combinations wherein the longitudinal and transverse wires are of different gage.

TABLE 2-9.—STYLES OF WELDED WIRE FABRIC
(Heavy-edge type)

Width	Longitudinal wires, spaced 6 in.							With cross wires spaced 6 in.			With cross wires spaced 12 in.			
	Number and gage			Sectional area, square inches									Total weight of fabric, pounds	
	Heavy wires, outer edge	Center wires	Heavy wires, inner edge	Total of heavy wires, outer edge	Total of center wires	Total of heavy wires, inner edge	Average of all wires per foot width of fabric	Gage	Sectional area, square inches per foot of fabric	Total weight of fabric, pounds per 100 sq. ft.	Gage	Sectional area, square inches per foot of fabric	Per 100 sq. ft.	Per square yard
Fabric 8 ft. 6 in. wide for 18-ft. roadway	2—0	14—6	2—0	0.148	0.405	0.148	0.082	6	0.058	48	6	0.029	38	3.4
	3—0	12—6	3—0	0.221	0.347	0.221	0.093	6	0.058	52	6	0.029	42	3.8
	4—0	10—6	4—0	0.295	0.290	0.295	0.104	6	0.058	55	6	0.029	45	4.1
	2—00	14—5	2—00	0.172	0.471	0.172	0.096	5	0.067	56	5	0.034	44	4.0
	3—00	12—5	3—00	0.258	0.404	0.258	0.108	5	0.067	60	5	0.034	48	4.3
	4—00	10—5	4—00	0.344	0.337	0.344	0.121	5	0.067	64	5	0.034	53	4.8
	2—000	14—4	2—000	0.206	0.558	0.206	0.114	4	0.080	66	4	0.040	53	4.8
	3—000	12—4	3—000	0.310	0.478	0.310	0.129	4	0.080	72	4	0.040	58	5.2
	4—000	10—4	4—000	0.413	0.399	0.413	0.144	4	0.080	77	4	0.040	63	5.7
Fabric 9 ft. 6 in. wide for 20-ft. roadway	2—0	16—6	2—0	0.148	0.463	0.148	0.080	6	0.058	48	6	0.029	38	3.4
	3—0	14—6	3—0	0.221	0.405	0.221	0.089	6	0.058	52	6	0.029	42	3.8
	4—0	12—6	4—0	0.295	0.347	0.295	0.099	6	0.058	55	6	0.029	45	4.1
	2—00	16—5	2—00	0.172	0.538	0.172	0.093	5	0.067	56	5	0.034	44	4.0
	3—00	14—5	3—00	0.258	0.471	0.258	0.104	5	0.067	60	5	0.034	48	4.3
	4—00	12—5	4—00	0.344	0.404	0.344	0.115	5	0.067	64	5	0.034	53	4.8
	2—000	16—4	2—000	0.206	0.638	0.206	0.111	4	0.080	66	4	0.040	53	4.8
	3—000	14—4	3—000	0.310	0.558	0.310	0.124	4	0.080	72	4	0.040	58	5.2
	4—000	12—4	4—000	0.413	0.478	0.413	0.137	4	0.080	77	4	0.040	63	5.7

All weights based on fabric 102 in. wide.

Miscellaneous Metals.—Steel and iron are the principal metals used in highways. Zinc, lead, tin, and copper with some others and their alloys are used in machinery, etc. Zinc is used to galvanize steel, tin to form tin plate, etc. Sheet copper, zinc, or lead should be used on all exposed work where corrosion is to be avoided.

WOOD

Wood is used in a variety of ways almost too numerous to mention. Many kinds of wood are available and employed in different parts of the country. It is impossible to list all or give their characteristics. The following are the principal groups.

1. Signs, fences, etc.: *pine, cypress, fir, etc.*
2. Posts, plain or treated: *cedar, fir, pine, oak, hedge, etc.*
3. Piles: *any suitable local wood, hardwoods preferred.*
4. Structural timbers: *yellow pine, Douglas fir, oak, etc.*
5. Forms: *any suitable low-priced dressed lumber, yellow pine, and fir are common.*
6. Floors and crossings: *untreated white oak, treated yellow pine, oak, pine, cypress, etc.*
7. Blocks: *yellow pine, Norway pine, cypress, gums, tamarack.*

Treatment.—Owing to the growing scarcity and increasing cost of wood every effort should be made to protect and preserve it. Signs, fences, buildings, etc., should be kept well painted. *Save the surface and you save all.* Lumber which is constantly submerged does not decay but all exposed wood which cannot be painted should be treated to preserve it. The two principal methods of treating are *creosoting* and *burnetizing.* Creosoting is the most common. The creosote oil is fungicidal and prevents decay. The free tar accompanying the creosote aids in filling the pores and prevents the entry of air and water. The creosote also retards or prevents the attacks of wood borers and insects, such as the teredo, the limnoria, and the termite.

The creosote may be applied by simply *painting* the surface with hot creosote oil. This method is applicable to small jobs and to materials so located or of such shape that they cannot be otherwise treated. Whenever treated timber of any kind is cut, the freshly exposed faces should be well painted with creosote to reseal the surface.

The *open-tank* process or *dipping* is used for fence posts, ties, telephone poles, etc. An open tank of suitable size is filled with hot creosote oil and the part of the wood to be treated is immersed in the tank and permitted to remain from a few minutes to an hour or more, depending on the depth of impregnation desired. The timbers are then removed and preferably cooled in a tank of cold oil.

The *full-cell* process of *pressure impregnation* is used for wood blocks, ties, bridge timbers, etc., which are to be used in exposed places under the most severe conditions. The seasoned timber, cut to size, is placed in large steel cylinders and subjected to alternate steam and vacuum for about an hour to soften the wood and draw out the moisture and juices. After a vacuum period, and without admitting air, creosote oil is pumped in and the pressure gradually increased to about 150 lb. per square inch at the end of the treatment. From 2 to 3 hours are required to give thorough impregnation. The oil is then pumped out and a slight vacuum, and sometimes a short steaming, applied to draw the excess oil from the surface to prevent bleeding. The timber is then withdrawn, cooled, and is ready for use. From 8 to 24 lb. of creosote oil per cubic foot of wood may be injected in this way. Normal treatment for posts, ties, and bridge timbers is about 12 lb. and for wood paving block about 16 lb. per cubic foot.

The *empty-cell* process is similar to the foregoing except in one particular. Just preceding the admission of the oil, air pressure of about 100 lb. per square inch is applied. Without breaking this pressure the oil is pumped in and the pressure raised to 150 to 200 lb. per square inch. The compressed air confined in the cells of the wood prevents them from filling with creosote, and when the treatment is completed this air drives the excess oil from the cells. In this way from 4 to 8 lb. of oil per cubic foot is absorbed. Such treatment is suitable for wood not to be exposed to the extremes of the weather, such as factory floors.

Burnetizing is done in a manner similar to creosoting. The preservative is a solution of zinc chloride. This salt is fungicidal and protects the wood against decay and to some extent against other destroying agencies. The chloride is soluble in water and where the wood is exposed to the weather it gradually leaches out and leaves the wood unprotected. This treatment is much used for conditions similar to that served by the empty-cell creosoting. *Kyanizing* is a similar treatment using mercuric chloride.

PAINT

Paint is an adhesive surface coating consisting of a *pigment* suspended in a *vehicle.* The vehicle hardens by oxidation or partial evaporation, leaving a thin coating of the pigment cemented to the surface.

Varnish is a coating consisting of a gum or resin dissolved in a solvent. On being applied to a surface, the solvent evaporates leaving a coating of the gum or resin. *Enamels* are essentially paints made of suitable pigments with varnish vehicles which dry very hard. Some require baking at low temperature. *Stains* are color pigments carried by thin vehicles which penetrate the surface leaving the color without forming a coating. They are analogous to dyes. *Lacquer* now refers to a variety of varnish in which the basic material is cellulose nitrate or cellulose acetate. Lacquers may be clear or contain a color pigment. *Duco* is the trade name of one such lacquer.

Pigments.—*Body pigments* give body to paint, while *color pigments* give color. The same material may perform both duties. The more common pigments used in highway paints are as follows:

White Lead.—Probably the most common pigment is white lead. It is usually basic lead carbonate, $2PbCO_3Pb(OH)_2$, but the basic sulphate, $PbSO_4PbO$, is also used. This pigment is white, forms an excellent body, and covers well. It is frequently combined with zinc white and forms the base for many colored paints.

Blue Lead.—A mixture consisting principally of lead sulphate, $PbSO_4$, and lead sulphide, PbS, with lesser amounts of the sulphite, oxide, and other materials is known as blue lead. Its color is a bluish gray but it tends to fade or change color in sunlight. It is an excellent body pigment, especially for bridge paints.

Red Lead.—A pigment which is much used for painting metals is red lead. It is essentially lead oxide, Pb_3O_4. Its color is a vermilion red when pure, but varying percentages of the lead monoxide litharge, PbO, often give it an orange tinge.

Zinc White.—Zinc white is zinc oxide, ZnO. It is a very opaque white pigment. It is frequently combined with white lead to add opacity and hardness. From 30 to 60 percent zinc white is used.

Lamp Black and Bone Black.—Lamp black and bone black are amorphous carbon pigments, dead black in color.

Chrome Yellow.—Normal lead chromate, $PbCrO_4$, is called chrome yellow. It is a brilliant yellow and is the principal yellow pigment used in paints for traffic signs. Various shades of *chrome orange* are obtained by adding different amounts of *chrome red* or basic lead chromate, $PbCrO_4 . PbO$.

Chrome Green.—Chrome green may be the chromic oxide or hydroxide, Cr_2O_3 or $Cr(OH)_3$, or mixtures of these with chrome yellow, Prussian blue, and lamp black.

Prussian Blue.—Prussian blue is a deep, brilliant blue pigment obtained from the reaction of potassium ferrocyanide and a ferric salt. It is used alone or in combination with other pigments.

Red Pigments.—Red pigments of various kinds exist. Most of those of sufficient brilliance for road signs are of organic origin.

Vehicles.—The principal vehicle is *linseed oil.* It hardens by oxidation. *Raw oil* hardens slowly. *Boiled oil* has been heated to the boiling point and oxidation started and therefore it dries quickly. It is usually of shorter life than raw oil. Various substitutes for linseed oil have been developed. Soybean oil seems to be the nearest competitor in quality and it can be produced at a lower price. The best of the other substitutes are nearly as expensive as linseed and the cheaper are not so good as soybean oil. Lacquers and varnishes are also used as vehicles.

Thinners.—Light oils added to reduce consistency are known as thinners. Turpentine, gasoline, benzene, kerosene, etc., are used with oil or varnish vehicles. Turpentine is the best but most expensive. Amyl acetate and similar solvents are used with lacquers.

Driers.—Driers are light oils which hasten drying partly by evaporation and partly by chemical action. *Japan drier* is the best. Thinners often apparently act as driers.

Manufacture.—Paints are manufactured by grinding the pigments, with sufficient oil, to a thick paste. The various pigments may be purchased in this form and mixed by hand with oil, driers, etc., to give desired color and consistency. *Prepared paints* are mixed and ground together by machinery to a normal consistency. Paints and paste pigments are packed in metal cans, buckets, or drums and in wooden kegs and barrels. The prices cover a considerable range and often fluctuate rapidly; hence no average figure can be given.

Water Paints.—Water paints are those using water as a vehicle. The hardening is accomplished essentially by the hardening of the pigments. *Kalsomine* has hydrated lime as its base. *Cement paint* has a portland cement base. *Fresco* is pigment mixed with glue. These paints are prepared dry and mixed with water just before using. They are little used in highway work.

Aluminum Paint.—Aluminum paint consists of finely divided metallic aluminum carried in a lacquer vehicle. It is highly durable and owing to its high reflecting power it has high visibility, especially at night. For these reasons it is gaining favor as a bridge paint.

Bituminous Paints.—Various paints, varnishes, pipe coverings, etc., are prepared from asphalts, tars, gilsonite, etc. Strictly they belong to the bituminous materials. The composition is variable and cannot be considered here. The colors are generally brown or black.

Applying Paint.—Paint is applied by dipping, by hand brushing, or with the air brush. Dipping can be done only where the article is of such character that it can be dipped into a vat. It works best with varnish vehicle paints. Hand painting requires paint of the right consistency and considerable work to rub the paint into proper contact. The air brush is simply a spray operated by compressed air. It is rather wasteful of paint but applies it well and is often economical. Old coats of paint may be removed by burning with a torch and scraping with wire brushes, with a sand blast, or with caustic soda.

MISCELLANEOUS

Cinders.—Cinders are much used in subbases for curbs and gutters, sidewalks, etc., and for light traffic streets and drives and sometimes in concrete. The best cinders are from steam boilers using bituminous coal. They are hard and vitreous, granular, porous, light, and durable. The cost is low since they are waste material. They can often be obtained for the cost of hauling.

Slag.—Crushed blast-furnace slag is much used in localities where available in place of crushed stone. Its characteristics are much the same as limestone but it is lighter, weighing about 75 lb. per cubic foot.

Crushed Brick.—Crushed hard-burned or vitrified brick forms an excellent aggregate. Its crushing and gradation should be the same as broken stone.

Oyster Shells.—Oyster and clam shells are found in certain localities. Composed principally of calcium carbonate they have the binding characteristics of good limestones but, being thin, lack toughness. They are used as a road surfacer and serve fairly well under moderate volumes and weights of traffic. Only raw or uncooked shells should be used. Shells which have been steamed or cooked to open them rapidly disintegrate.

Gypsum.—Gypsum is essentially calcium sulphate. Certain varieties have high binding values and are useful in sand-clay, and gravel construction. In some locations gypsum mixed with soil is found and forms a good surfacing material for light traffic roads.

Marl.—Marl is principally calcium carbonate mixed with clay. When the lime content is high it bonds well and may be used as a road surfacer or as a binder in sand-clay or gravel.

Haydite.—Haydite is a patented concrete aggregate made by rapidly burning suitable uncompacted clay or shale. It forms a sort of clinker resembling cement clinker in appearance and may be crushed to suitable size. It is light in weight, rivaling cinders, and is hard, tough, and durable. It forms a concrete comparable in strength with stone or gravel. It is especially suitable where low weight is important, such as floors and roofs.

Novaculite.—Novaculite is a gravel found in the Ozark region, especially southern Illinois. It consists of silica, clay, and iron oxide. The silica appears largely as novaculite rock. It possesses unusual binding properties and is an excellent road material.

Caliche.—Caliche is a calcareous material found in Arizona and other regions of the Southwest. Its road-building characteristics are similar to novaculite except that it is somewhat dustier.

Walite.—Walite is a patented concrete aggregate made from slag. It is somewhat lighter in weight than haydite and is also light in color where haydite is dark. It has the same uses.

CHAPTER 3

BITUMINOUS MATERIALS

Bituminous materials are those in which bitumens are the essential and predominating components. *Bitumen* may be defined as a mixture of natural or pyrogenous hydrocarbons totally soluble in carbon disulphide. The hydrocarbons may be gases, liquids, or solids and are often accompanied by their own non-metallic derivatives.

Classification.—Bituminous materials are broadly classified as oils, asphalts, and tars.

Oils are liquid bituminous materials generally obtained from petroleum but the name is also applied to certain tar distillates.

Asphalts are solid or semisolid cementitious bituminous materials which occur in this form in nature or which are obtained by refining petroleum. They are termed *native* or *natural asphalts* when found in nature and *oil asphalts* when manufactured from petroleum.

Tars are liquid to semisolid bituminous condensates produced by the destructive distillation of organic materials such as coal, oil, or wood and which yield *pitch*, or solid material, on partial evaporation or fractional distillation.

Bituminous road materials are further classified according to use as follows:

Dust preventives are light[1] oils used primarily for the prevention or suppression of dust.

Road oils are heavy[1] oils, largely asphaltic in character, used principally in the treatment of earth, sand-clay, and gravel roads. *Fluxes* are heavy asphaltic oils used for softening hard asphalts to suitable consistencies. A *primer* is a light tar or liquid asphalt used as a first application to promote the adhesion of a heavier material applied later.

Carpeting mediums are heavy oils to semisolid materials used with small-sized aggregates to form thin protective coverings on road surfaces.

[1] Light and heavy as applied to oils do not refer to weight but to viscosity; *i.e.*, a light oil is mobile; a heavy oil is sluggish or viscous.

Bituminous cements are semisolid to solid materials used as binders in bituminous road surfaces. Tar products are known as *tar* or *pitch,* while asphaltic materials are termed *asphalt cements.* There is a tendency to limit the term *cement* to those binders which require heating to make them fluid. *Fillers* are hard cements used to fill cracks, joints in block pavements, etc.

- Bituminous Materials
  - Gases
    - Natural
    - Artificial
  - Petroleum *Native liquid bitumen*
    - Crude
      - Paraffin base—*paraffin oil*
      - Mixed base—*semiasphaltic oil*
      - Asphalt base—*asphaltic oil*
      - Maltha—*liquid asphalt*
    - Liquid products
      - Very light volatile liquid
      - Lubricating oils
      - Motor fuels and burning oils
      - Heavy fuel oils
      - Road oils
      - Fluxes
    - Solid and semisolid products
      - Mineral waxes, etc.
      - Greases
      - Carpeting mediums
      - Asphalt cements
  - Natural asphalts *Native solid and semi-solid bitumens*
    - Trinidad
    - Bermudez
    - Mexican
    - Miscellaneous
    - Rock asphalt
    - Gilsonite
    - Grahamite
  - Tars *Pyrogenous bitumens*
    - Crude
      - Gas-house
      - Coke oven
      - Water gas
    - Refined
      - Light volatile oils—*benzine*
      - Motor fuels, etc.
      - Wood preservatives
      - Road tars—*Tarvia, Tarmac*
      - Pitch

FIG. 3-1.—Classification of bituminous materials.

Powdered asphalt is an asphalt cement so hard that it can be pulverized to a fine powder. It is generally used in a cold mix together with a fluxing oil which gradually combines with the hard powdered material forming a binder of suitable consistency.

Cold-mix or *cold-patch* materials are bituminous cements so prepared that they can be used without heating. A *cutback* is made by thinning the cement, either tar or asphalt, with a

light, volatile oil to a suitable consistency. It hardens by the evaporation of the solvent. An *emulsion* consists of very fine globules of bituminous material, generally asphaltic, suspended in water by the aid of an emulsifying agent such as soap. It sets by the *breaking* of the emulsion which releases the water and permits the bitumen to coalesce into a film, the water then evaporating.

Figure 3-1 gives in outline form a general classification of the principal bituminous materials of interest to the road builder.

OIL ASPHALTS

Petroleum.—Petroleum or mineral oil is widely distributed throughout the world. It occurs most commonly in *pools* in

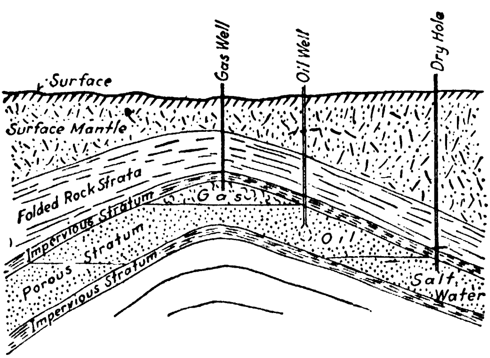

FIG. 3-2.—Cross-section of oil and gas dome.

porous sandstones or limestones which lie on top of, and are covered by, impervious strata of rock or shale. The pools are usually located in *domes* along the crest of anticlines although occasionally they are found on the slopes and more rarely in the synclines. Frequently, the tops of the domes are filled with gas and almost invariably salt water underlies the oil. Figure 3-2 gives a diagrammatic cross-section of an oil field. Wells are drilled from the surface to tap the oil pool. In most cases a sump must be formed at the foot of the casing, which is done by shooting the well with nitroglycerine in quantities from 40 to 500 qt. The result is to shatter the rock so as to form a cave with porous walls into which the oil seeps. Occasionally the pressure is so great that the oil is forced out at the surface and a gusher results but in most cases the oil must be pumped. Petro-

leum is also found impregnating shale beds but the shale-oil industry has not been greatly developed.

Kinds.—*Paraffin-base* oils are found in eastern United States. They yield no asphaltic materials but abound in bitumens of the paraffin series useful in lubricating oils, greases, waxes, etc.

Mixed base or *semiasphaltic* oils constitute the bulk of the mid-continent crudes. They yield both greasy and asphaltic residues and are modified for road purposes by cracking and blowing.

Asphaltic-base oils like those of California, Texas, and Mexico yield little or no lubricants and large percentages of asphaltic products.

Maltha is a very viscous petroleum, being essentially a liquid asphalt. It is often used as a flux.

Transporting and Refining Petroleum.—The oil from the wells is pumped to storage tanks and from these it is transported to the refineries in *tank cars* or, more frequently, by pumping through *pipe lines*. The crude oil is stored in steel tanks holding 80,000 bbl. or more, which are covered to prevent evaporation. Elaborate precautions are taken to prevent fire but occasionally a costly fire does occur.

Refining is the process of dividing the crude oil into the various commercial products. It may consist in simple fractional distillation with or without the various fractions being further refined and treated for the market. Most modern refining, however, resorts to *cracking*, a process that breaks down the complicated structure of some of the molecules of the bitumens. Cracking results in an increased output of light products (gasoline) for which there is the greater demand and consequently a higher price. At the same time it modifies the residue.

Cracking is accomplished at higher temperatures, usually with increased pressure, and frequently in the presence of steam. A judicious use of cracking coupled with *blowing* may furnish asphaltic and other materials superior to straight distillation. Blowing consists of passing air through the heated oil in the still. It aids cracking and also partially oxidizes some of the compounds giving them different characteristics.

Asphaltic Products.—Road oils, carpeting mediums, asphalt cements, fillers, etc., are prepared from the heavy residues of the refining process. Formerly little used, oil asphalts are now used in 90 percent or more of all asphaltic road work. In addition to road building, oil asphalts and their modifications are used in

TABLE 3-1.—LIQUID ASPHALTIC ROAD MATERIALS

Properties	Material type												
	SC-1	*SC*-2	*SC*-3	*SC*-4	*MC*-1	*MC*-2	*MC*-3	*MC*-4	*MC*-5	*RC*-1	*RC*-2	*RC*-3	*RC*-4
Test requirements:													
Water and sediment, percent	2.0−	2.0−	2.0−	2.0−									
Flash point, °F	150+	200+	200+	250+		150+	150+	150+	150+	80+	80+	80+	80+
Viscosity, Saybolt Furol at 77°F., sec	20 to 150				40 to 150								
Viscosity, Saybolt Furol at 122°F., sec		200 to 320								80 to 160	200 to 400		
Viscosity, Saybolt Furol at 140°F., sec			150 to 300	350 to 550		150 to 250	300 to 500	500 to 800				275 to 400	700 to 1400
Viscosity, Saybolt Furol at 180°F., sec									170 to 280				
Total distillate to 374°F., percent by volume										5+			
Total distillate to 437°F., percent by volume		2−	2−	2−	10−	2−	2−	1−	1−	12+	10+	3+	0.5+
Total distillate to 600°F., percent by volume		15−	10−	8−	25+	10–20	8–20	16−	14−	25+	20+	14+	7+
Total distillate to 680°F., percent by volume	50−	25−	20−	18−	50−	27−	25−	25−	20−	40−	35−	30−	25−
Float of residue, 122°F., sec	50−	25+	25+	25+									
Penetration of residue, 100 g., 5 sec., 77°F					70 to 300	100 to 300	100 to 300	100 to 300	100 to 300	60 to 120	60 to 120	60 to 120	60 to 120
Ductility of residue, 77°F., cm					60+	60+	60+	60+	60+	60+	60+	60+	60+
Solubility of residue in CS_2, percent	99.0+	99.0+	99.0+	99.0+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+
Recommended uses:													
Dust layer	X												
Primer					X								
Surface treatments										X			
Mixed-in-place construction:													
Aggregate densely graded[1]		X	X[5]			X							
Aggregate, open graded[2]											X	X[5]	
Coarse aggregate[4]												X	
Plant-mixed construction:													
Aggregate densely graded[1]			X	X			X						
Aggregate, open graded[2]											X	X	
Aggregate, open graded[3]								X	X				
Coarse aggregate[4]												X	X

[1] Maximum size not over 1 in. Fairly uniform grading from coarse to fine with appreciable percentage passing No. 200 sieve.
[2] Maximum size not over 1½ in. Fairly uniform grading from coarse to fine with little or no material passing No. 200 sieve.
[3] Maximum size not over 1 in. Fairly uniform grading from coarse to fine with little or no material passing No. 200 sieve.
[4] Maximum size not over 1½ in. Little or no material passing 34-in. screen.
[5] Under favorable conditions only.

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making paints, roofings, building papers, sealing compounds, pipe coatings, and for hundreds of other purposes in industrial processes.

Table 3-1 gives the technical specification for liquid asphaltic road materials. *SC* indicates slow-curing, *MC* medium-curing, and *RC* rapid-curing types. Table 3-2 gives similar specifications for asphalt cements and fillers.

NATURAL ASPHALTS

Natural asphalts are found in many regions of the earth. The deposits vary from springs of maltha to large beds of almost rock-like material. The earliest use of asphalt was from these natural supplies and dates back almost to the dawn of civilization. Practically none of the natural asphalts are found ready for use in modern work; hence they must be refined and fluxed to a desired consistency. Formerly, natural asphalts formed the bulk of the asphalts used for paving purposes, but practically none are now used in the United States.

Trinidad Asphalt.—The best-known natural asphalt is that from the famous Asphalt Lake on the Island of Trinidad. This deposit covers some 125 acres to a depth of more than 125 ft. It is apparently fed by deep springs of maltha. The material in this lake is mixed with vegetable matter, water, fine sand, and clay and must be refined. The refined product differs from almost every other known asphalt in that it contains a large amount of extremely fine mineral matter. The pure bitumen averages only about 56.5 percent. The material is too hard to be used directly and must be fluxed.

Trinidad asphalt is cut out of the lake in chunks with picks, loaded into tram cars and conveyed to the port where it is either refined or loaded into ships and transported to a refinery at Maurer, N. J. The crude asphalt is heated in tanks by steam coils and agitated with steam jets. The water and gas are thus driven off. The light sticks, leaves, etc., float to the surface and are removed, while the heavy mineral matter settles to the bottom to be removed later. The refined material is drawn off into barrels for shipment to the job where it is melted and fluxed to the desired consistency. A harder and less pure asphalt is found around the edges of the lake. It is termed *land asphalt* in contradistinction to the *lake asphalt* and is used to a limited extent.

A heavy asphaltic petroleum or maltha is also found in Trinidad and is refined into excellent flux and carpeting mediums.

Bermudez Asphalt.—The Bermudez deposit is on the north coast of Venezuela. Its area is larger than Trinidad Lake, covering some 900 acres; its depth is only about 7 ft. The asphalt is mixed with water, sand, clay, and vegetable matter, but the bitumen content is high, averaging about 95 percent in the water-free material. Bermudez asphalt must be fluxed and is widely used in sheet asphalt, asphalt concrete, and asphalt macadam pavements. Refining is similar to that of the Trinidad.

Miscellaneous Deposits.—Cuba possesses several deposits of asphalt not as yet fully developed. The material somewhat resembles the Trinidad and contains 65 to 75 percent bitumen.

FIG. 3-3.—Bermudez asphalt lake.

Several deposits are found along the Gulf Coast of Mexico. They are variable in character containing from 60 to 90 percent bitumen.

Historically, the Dead Sea deposits are the oldest and best known, dating from earliest Bible times, but they have not been developed to any extent. Other deposits occur in various parts of Asia, Europe, South America, Texas, and California.

Gilsonite.—Gilsonite is a very pure bitumen found in Colorado and Utah. It is very hard and brittle and differs considerably from the ordinary asphalt and is frequently considered not an asphalt. It forms a tough rubbery bituminous cement when fluxed. It is often used to enrich poor oil asphalts. It is largely used in other industries and especially in paints, pipe coatings, etc. *Grahamite* is a similar material.

TABLE 3-2.—SUMMARY SPECIFICATIONS OF THE A.S.T.M. FOR VARIOUS KINDS OF ASPHALT FOR ROAD WORK

Type of pavement	Asphalt macadam			Manufacture of asphalt block		Asphalt filler for brick pavements	Sheet asphalt and asphaltic concrete					Method of test
									And as filler for brick and block pavements	And as filler for block pavements	And asphalt macadam and as filler for block pavements	
A. S. T. M. serial designation	D102-24T	D103-24T	D135-23T	D133-23T	D134-23T	D241-26T	D163-23T	D164 23-T	D99-26T	D100-26T	D101-26T	
Penetration, 25°C., 100 g., 5 sec.	85–100	100–120	120–150	10–15	15–25	30–50	25–30	30–40	40–50	50–60	60–70	D5
Penetration, 0°C., 200 g., 1 min.						10 minimum						D5
Penetration, 46.1°C., 50 g., 5 sec.						110 maximum						D5
Flash point, open cup, degrees Centigrade, minimum	175	175	175	200	200	200	175	175	175	175	175	D92
Softening point, ring-and-ball method, degrees Centigrade						65–110						
Loss at 163°C., 50 g., 5 hours, percent maximum	2	2	2	1	1	1	2	2	2	2	2	D6
Penetration of residue, percent of original, minimum	60	60	60	50	50	60	60	60	60	60	60	D5
Ductility, centimeters, not less than	30	30	30	5–15	5–20	3	15	25	30	30	30	D113
Proportion of bitumen insoluble in carbon tetrachloride, percent	1	1	1	1	1	1	1	1	1	1	1	D165

NOTE.—When less than 99 percent of asphalt cement is soluble in carbon tetrachloride, the percentage of bitumen (solubility in carbon disulfide) shall be reported.

Rock Asphalt.—Limestone or sandstone naturally impregnated with asphalt or maltha is known as rock asphalt. Such deposits occur in many places and have been much used for pavements, sidewalks, floors, etc., especially in Europe. The principal American deposits are in Kentucky, Oklahoma, Texas, and California. The rock asphalts vary greatly in character and even in the same deposit, and practically none are naturally proportioned for road work. The majority require blending of portions from different parts of the quarry or the admixture of either bitumen or sand to produce uniform and satisfactory asphalt content. *Kyrock* is the trade name of a typical rock asphalt produced in Kentucky.

TARS

Coal Tar.—Coal tar is the bituminous condensate from the destructive distillation of bituminous coal.

Gas-house tar and coke are byproducts from the manufacture of ordinary illuminating gas from coal. *Coke-oven tar* and gas are byproducts in the preparation of metallurgical coke in the byproduct coke oven. Other important byproducts from both processes are benzol and ammonium sulphate. A ton of good coal in a byproduct oven will yield about 1,425 lb. of coke, 10,500 cu. ft. of gas, 2 gal. of crude benzol, 19 lb. of ammonium sulphate, and 7½ gal. of crude tar.

Gas-house and coke-oven tars differ somewhat in their composition and characteristics on account of differences in the processes from which they are obtained. These differences, however, are unimportant from the standpoint of use in road work.

Water-gas Tar.—Water-gas is made by passing steam through incandescent coke. This gas alone is not satisfactory for domestic use; hence it is enriched with gas made by the destructive distillation of oil at very high temperatures. Water-gas tar is a byproduct in this process. It partakes of the characteristics of both coal tar and asphalt and hence will mix more or less readily with either. Water-gas tars have changed greatly in character in recent years because of changes in the water-gas process.

Refining Coal Tar.—The crude tar is first dehydrated and then fractionally distilled. The *first runnings* up to 105°C. contain water, ammonia, and a little volatile oil. *Light oil* between 105 and 210°C. is generally redistilled, the part below 170°C.

TABLE 3-3.—TECHNICAL SPECIFICATIONS FOR ROAD TARS

	Prime coat		Cold surface treatment		Retread		Hot surface treatment		Crack filler and penetration		Cold patch	
	TC-1	*TC*-2	*TC*-3	*TC*-4	*TM*-1	*TM*-2	*TH*-1	*TH*-2	*TP*-1	*TP*-2	*TCP*-1	*TCP*-2
Specific gravity at 25°C	1.11 to 1.18	1.11 to 1.18	1.13 to 1.19	1.13 to 1.19	1.14 to 1.22	1.14 to 1.22	1.18 to 1.24	1.18 to 1.24	1.20 to 1.26	1.20 to 1.26	1.14 to 1.20	1.14 to 1.20
Specific viscosity at 40°C	8 to 13	13 to 18	18 to 25	25 to 35	...	...	...	...	...	...	35 to 60	60 to 80
Specific viscosity at 50°C. (Engler)	...	...	...	...	16 to 22	26 to 36						
Float test at 32°C., seconds	...	...	...	...	...	...	60 to 150	150 to 210				
Float test at 50°C., seconds	...	...	...	...	...	...	...	...	100 to 160	160 to 220		
Total distillate, percent by weight:												
To 170°C	0 to 7	0 to 7	0 to 5	0 to 5	0 to 5	0 to 5	0 to 1	0 to 1	0 to 1	0 to 1	1 to 8	1 to 8
To 235°C	...	...	...	...	...	...	...	...	...	...	8 to 20	8 to 20
To 300°C	0 to 40	0 to 40	0 to 40	0 to 40	0 to 32	0 to 32	0 to 25	0 to 25	0 to 20	0 to 20	36	36
Softening point of residue, °C	60	60	60	60	60	60	65	65	65	65	65	65
Specific gravity of distillate at 38°C. (minimum)	0.96	0.96	0.98	0.98	0.98	0.98	1.01	1.01	1.02	1.02	0.94	0.94
Bitumen, soluble in carbon disulphide, percent	89 to 98	89 to 98	89 to 98	89 to 98	89 to 98	89 to 98	80 to 95	80 to 95	80 to 95	80 to 95	80 to 95	80 to 95
Water, per cent by volume (maximum)	2.0	2.0	2.0	2.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0
Application temperature, °F	60 to 125	60 to 125	80 to 150	80 to 150	80 to 150	80 to 175	175 to 225	175 to 225	200 to 250	200 to 275		

forming crude naphtha from which *benzol* is obtained, while the remainder is added to the next fraction. The *carbolic oil* between 170 and 235°C. contains phenol and naphthalene. Between 235 and 270° is obtained the *creosote oil* high in cresols and used for wood preserving. *Anthracene oil* is obtained above 270 to about 300°C.

These various fractions are sold to manufacturing chemists who prepare the more than 1,200 products of coal tar, including dyes, explosives, medicines, flavorings, etc. The heavy residue in the still may be further distilled or may be fluxed or cutback with lighter distillates and thus prepared as road or industrial tars and pitches.

Road Tars.—Practically all coal tars in the United States are refined by The Barrett Company or the Koppers Products Company. These companies market their road tars under the trade names of *Tarvia* and *Tarmac*, respectively. Table 3-3 gives the technical specifications under which these road tars can be obtained for different purposes.

ANALYSIS OF BITUMINOUS MATERIALS

Total Bitumen.—Since bitumen, by definition, is soluble in carbon disulphide, the analysis for total bitumen is simply to dissolve the material in CS_2 and filter the solution to remove the insoluble material. Usually this filtering is done through an asbestos felt mat in a Gooch crucible so that the percentage of organic matter in the insoluble material may be determined by igniting the residue (A.S.T.M. test D4-27).

Asphaltenes.—Asphaltenes are the components of bitumen which are insoluble in 86°Bé. (specific gravity = 0.647) paraffin naphtha.[1] The process of determining the asphaltenes (*U.S. Dept. Agr. Bull.* 1216) is the same as the determination of total bitumen except for the different solvent and also in that the result is based on the total bitumen present and not on the total sample. Asphaltenes are thought to give cementing properties to the compound.

Carbenes.—Carbenes are the portions of the bitumen insoluble in carbon tetrachloride, CCl_4. The determination is made the same as for asphaltenes except for the solvent (A.S.T.M. D165-27).

[1] This material is listed by chemical companies as *petroleum ether*, the correct grade having a boiling point of 40 to 50°C.

Carbenes are inert, much like coke, and usually indicate damage by overheating. The permissible percentage is therefore limited.

Various Solubility Tests.—Similar solubility tests in various solvents such as chloroform, ether, or benzol are sometimes required but their meaning is not clear and they are little used in road work. Solubility in benzol and chloroform are common tests, however, for creosote wood preservatives.

Fixed Carbon.—Fixed carbon is that portion of the material which forms coke on destructive distillation away from the presence of oxygen. The determination is not accurate. The amount of fixed carbon is thought to exert an influence on the physical qualities of the material and therefore may be limited by specification (*U.S. Dept. Agr. Bull.* 1216).

Free Carbon.—Free carbon is the organic matter in tar which is insoluble in carbon disulphide. The amount is determined by igniting the residue from the total bitumen test. It exists as a finely divided, amorphous black powder resembling soot. It is not pure carbon, however, but is apparently composed largely of hydrocarbons very rich in carbon which result from cracking of the original hydrocarbons during the formation of the tar.

Free carbon tends to increase the specific gravity, raise the softening point, reduce the susceptibility to temperature changes, and develop hardness and mechanical stability. On the other hand, it reduces the cementing power. Its general behavior is similar to the mineral filler used in asphaltic paving mixtures. *High-carbon tar* contains more than about 12 to 15 percent of free carbon and is used for block pavement fillers, etc. *Low-carbon tar* is more cementitious and is used for road binders.

Softening Point.—Bituminous materials do not have a definite melting point but gradually soften with increased temperature until changed into liquids. The softening point is an arbitrarily determined temperature representing this point of transition from solid to liquid.

The *ring-and-ball* method (A.S.T.M. D36-26) is generally used for asphalts and occasionally for tars. A sample 5/8 in. in diameter and 1/4 in. thick is molded in a brass ring. The ring and sample are cooled and then suspended in a beaker containing water or glycerine. A 3/8-in. steel ball is placed on the sample and the temperature raised at the rate of 5°C. per minute. The softening point is taken when the sample has dropped 1 in. out of the ring.

The *cube method* (A.S.T.M. D61-24) is commonly used for tars. Its general procedure is the same as the preceding method except that the sample is a ½-in. cube impaled on the horizontal leg of a bent wire.

Volatilization.—Bituminous road materials must retain their initial properties indefinitely. One of the principal changes is due to the evaporation of light oils. Materials must therefore contain as little volatile oils as possible at the consistency desired. The test is made by submitting a 50-g. sample to a temperature of 163°C. for 5 hr. under standard conditions and determining the loss in weight and also the change in consistency. This test is usually designated as *loss at* 163° *for* 5 *hr.* (A.S.T.M. D6-33).

Penetration.—Penetration is the method of measuring the consistency of solid and semisolid bituminous materials. It consists of measuring the distance a standard needle will penetrate the material under a given load for a given time. *Normal penetration* is made at a temperature of 25°C. with a load of 100 g. applied for 5 sec. on a standard needle (A.S.T.M. D5-25). Penetration is given in units of $\frac{1}{10}$ mm., often termed *points* or *degrees*. Penetration is made on an asphalt before and after volatilization to determine the change in consistency.

Viscosity.—Viscosity is the measure of consistency of liquid materials. It consists essentially of determining the time required for a certain amount of oil to flow through a standard orifice at a given temperature.

Lubricating oils are tested in the *Saybolt Universal* viscosimeter and the viscosity is given by the time in seconds for 60 cc. to pass the orifice at the desired temperature (A.S.T.M. D88-36). The *S.A.E. viscosity numbers* for motor oils are based on this test. They form a purely arbitrary but convenient scale for designating suitable ranges of viscosity.

Road oils, etc., are tested in the *Saybolt-Furol* viscosimeter, the procedure being the same as for lubricating oils (A.S.T.M. D88-36). Suitable temperatures are chosen for the different products. The *Engler* viscosimeter was formerly used (*U.S. Dept. Agr. Bull.* 1216). The results were given in *specific viscosity* which is the time required for 50 cc. of the oil to pass the orifice divided by the time required for 50 cc. of water to pass. This test is still generally used for tars.

Float Test.—The float test (A.S.T.M. D139-27) is presumably a test of consistency of intermediate tar materials. An aluminum

float with a plug of the bituminous material in the bottom is placed in warm water and the time for the plug to loosen and admit water is taken as a measure of consistency.

Ductility.—Ductility is a measure of the cohesive properties of a bituminous material. A specimen with a breaking section of 1 sq. cm. is molded and cooled to 25°C. It is then stretched in a special machine at a constant rate. The length at which the specimen breaks is taken as the measure of its ductility. The normal rate of stretch is 5 cm. per minute, but some specifications require 60 cm. per minute which makes a difference in the measured ductility. Oil asphalts show high ductility, natural

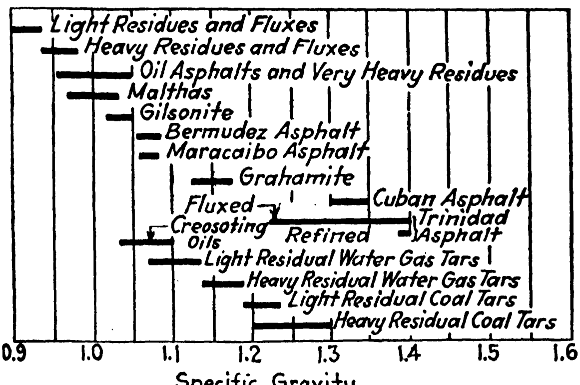


FIG. 3-4.—Specific gravity of bituminous materials.

asphalts intermediate values, while blown fillers are *short* or have low ductility (A.S.T.M. D113-35).

Fractional Distillation.—Fractional distillation (A.S.T.M. D20-30) was formerly made on tar products only but is now also being applied to asphaltic materials, especially the liquid or cutback types. Suitable temperature limits for different fractions are selected in accordance with the type of material. The amount of the different fractions present indicates the character of the material.

Specific Gravity.—Specific gravity is useful in identifying materials and in computations but has no merit per se. It is made by means of hydrometers for liquids, specific gravity bottles for intermediate materials, or direct displacement for solids. The specific gravity of very light distillates such as gasoline and kerosene is conveniently made with a Westphal balance (A.S.T.M. D70-27, D71-27, D287-36).

Figure 3-4 gives diagrammatically the specific-gravity range of the more common bituminous materials.

Flash and Fire Points.—The *flash point* is the temperature at which sufficient inflammable vapor is given off to flash for an instant when an open flame is applied to the surface of the material. The *fire point* is the temperature at which sufficient vapor is given off to ignite and burn for at least 5 sec.

Low flash and fire points indicate the presence of considerable quantities of volatile oils and thus help in the identification of cutbacks. High flash points indicate the absence of volatiles and hence a stable material and is to be expected of asphalt cements and of good motor oils. The flash and fire points are also of use in indicating the safe temperatures to which materials can be heated or the necessity for keeping open flames away.

The test is made by heating about a 68-cc. sample in a special test cup at a uniform rate and applying a test flame to the surface at intervals. When a distinct flash occurs the temperature is read from a thermometer whose bulb is immersed in the material. The heating is continued until the fire point is reached. Either the *Cleveland open cup* (A.S.T.M. D92-33) or the *Tagliabue open cup* may be used.

Dehydration.—It is often desired to determine the amount of water which may be entrained in a bituminous material or which may have been intentionally incorporated as in an emulsion.

This can be done accurately by heating a suitable sample carefully in a small still and condensing the water driven off (A.S.T.M. D95-30). Generally the sample is cutback with gasoline to aid in the separation. The method has to be modified for emulsions and calcium chloride is sometimes used to help break the emulsion. Another method suitable primarily for crude materials is by means of a centrifuge (A.S.T.M. D96-35).

PRE-MOLDED EXPANSION JOINTS

Pre-molded asphaltic expansion joint fillers are now almost universally used in pavement and sidewalk work. The sheets of filler are prepared in any desired thickness and suitable dimensions. They are easily set in place and the concrete or other material deposited against them. With reasonable care in placing, a perfect joint is easily obtained. There are three general types of pre-molded filler.

Plain Type.—The plain asphalt type consists of sheets of asphalt cement of suitable consistency cut to desired shape. This type is not satisfactory for road work since the asphalt softens in warm weather and the sheets sag and warp and are hard to place, while in cold weather they become brittle and break in handling. The material is subjected to the regular tests for asphalts.

Fiber Type.—The fiber type has the asphalt stiffened by the addition of 20 to 25 percent by weight of wood fiber. The sheets are easy to handle and install. They take up the expansion well but if partially squeezed out of the joint have a tendency to break off instead of being ironed out flat by traffic. The amount of fiber may be determined by dissolving the sample in carbon disulphide and filtering through a coarse filter or fine screen. The CS_2 may be evaporated off and the regular asphalt tests made on the residue.

Sandwich Type.—The sandwich type consists of a sheet of asphalt, sometimes containing fiber, placed between two thin stiff sheets of impregnated cardboard or felt. These outside sheets serve as stiffeners. This type is as easy to handle as the preceding, does not break off easily, and is more of a *bleeding joint; i.e.*, the asphalt when squeezed out flows over and is rubbed down by traffic, thus sealing the joint. The outside of the sheets is often coated with a soft adhesive asphalt cement to increase adhesion with the pavement. Tests are made in the same manner as with the fiber type. Mechanical tests for stiffness, strength, etc., may also be made on any of the three types.

CHAPTER 4

CONCRETE

Concrete is an artificial stone made by cementing together a mineral aggregate with portland cement.

Strictly, any cementing medium may be employed to form a concrete but portland cement is so familiar to everyone that the word *concrete* immediately suggests its use and, therefore, the foregoing definition is the common one. If other cements are used the concrete is so designated, *e.g.*, *natural cement concrete*, *asphalt concrete*. Occasionally the term *portland-cement concrete* is used to avoid ambiguity.

Similarly, the word *cement* is commonly used to indicate *portland cement* except where the longer term is necessary to avoid ambiguity. All other cements are described by some modifying term.

Concrete may be further classified by the kind of aggregate used as *gravel concrete*, *cinder concrete*, *slag concrete*, etc.

Ingredients.—The materials required to make concrete are cement, aggregate, and water. The cement is the strength-giving element, the aggregate constitutes the body or bulk of the concrete, while the water serves a dual purpose. First, it acts as a mixing medium forming a plastic mass of the mixture and, second, it reacts with the cement causing it to set and harden. It is evident that the individual characteristics of each ingredient, as well as the manner in which they are combined, must have a decided effect on the character of the finished concrete.

Proportions.—The cement is the most expensive element of the concrete; hence no more of it should be used than is necessary to give the desired strength. On the other hand, lean mixtures are harsh and hard to finish while rich mixtures are smooth, plastic, and easily worked. Enough cement must, therefore, always be used to give a mixture that can be well placed and properly finished, and not infrequently this consideration is of greater importance than strength in determining the amount of cement.

The aggregate is less expensive than the cement and, therefore, it is desirable to use as much of it as possible. The greatest strength with the least cement is obtained when each particle of the aggregate is completely covered with cement and the spaces between the particles sufficiently filled with cement to act as a tie between the grains. Since the area to be covered, in proportion to the volume, decreases as the size of particle increases, and since the spaces to be filled decrease as various sizes are mixed together, it follows that the best concrete is obtained when the aggregate is *coarse* and *well graded.*

For convenience in preparation, handling, and proportioning, the aggregate is usually divided into two parts, known as *coarse aggregate* and *fine aggregate.* Natural *sand* is almost universally used for the latter while natural pebbles (*gravel*) or artificially *crushed stone* are used for the former. To the man on the job, however, who cares little for the refinement of terms the aggregates become *sand* and *rock,* which terms are decidedly convenient and expressive if not always absolutely accurate. The amount of *water* required is properly a part of the problem of proportioning but for convenience is discussed under *consistency.*

Methods of Proportioning.—Various methods for proportioning the ingredients in concrete have been developed. All of them have some merits and some demerits, and even the best of them are far from complete and are often cumbersome to use.

The *voids method* is based on the premises that the voids in the aggregates should be entirely filled with cement, and that all the grains should be coated with cement. The percentage of voids in the sand and rock are determined by any convenient method. The amount of cement is made about 20 percent greater than the voids in the sand to compensate for the increase in voids due to the pushing apart of the grains by the cement which gets between them. The mixture of cement and sand is then considered as a mortar and a sufficient amount of it is allowed to fill the voids of the rock plus a similar excess which may vary from 10 to 15 percent of the voids in the coarse aggregate. No consideration is given to the amount of water and no estimate is made of the probable strength of the concrete.

The *water-cement-ratio,* or *Abrams,*[1] *method* states that, within the limits of a workable mix, the strength of the resulting concrete

[1] *Bull.* 1, Structural Materials Lab., Lewis Inst., Chicago.

may be considered as measured by the water-cement ratio, *i.e.*, the ratio of the volume of the water to the volume of the cement in the fresh concrete. Further, variations in gradation of aggregate, changes in the amount of cement, etc., may, within these limits, be considered simply as devices for securing a desired workability or consistency with a minimum of water. By means of formulas, tables, or diagrams the relative amounts of cement, water, sand, and rock may be determined. This method takes into consideration the amount of mixing water and makes an estimate of the strength to be expected of the concrete. It is somewhat cumbersome to use and its greatest value has been in establishing the great importance of properly proportioning the water as well as the other materials. The *trial-batch* method is a modification of the Abrams method. A water-cement ratio to give the desired strength is selected in accordance with Abrams' data. This fixes the amount of cement and water for each batch. Trial batches are then mixed until the amounts of sand and rock which give a concrete of suitable consistency and workability are found.

The *mortar-voids*, or *Talbot's*,[1] method is, perhaps, the most scientific scheme yet devised. It establishes a relation between the density of the finished concrete and its strength, calculating the density from the absolute volumes of the ingredients, including the water. It thus proportions the water as well as the other materials and estimates the resulting strength. Although its application is somewhat cumbersome, the results are dependable and consequently it is gaining in favor in all kinds of important work.

The *cement-sand-ratio method* assumes that the strength of the concrete is controlled by the strength of the mortar, provided that there is always enough mortar to fill completely the voids in the coarse aggregate, and therefore the strength of the concrete is the same as long as the cement-sand ratio is kept constant. This method is quite useful in determining how to proportion bank-run or other ready-mixed aggregates.

Empirical proportioning is the most familiar method. Experience and experiment have shown that if the characteristics of the aggregates are limited, and if reasonable consistency is used, certain proportions will yield concrete of sufficient strength and desired working qualities for different kinds of work. This

[1] *Bull.* 137, Eng. Exp. Sta., Univ. Illinois.

TABLE 4-1.—RECOMMENDED WATER CONTENT[1] FOR CONCRETE TO MEET DIFFERENT DEGREES OF EXPOSURE

Exposure	U. S. gallon per sack above, water-cement ratio below		
	Reinforced piles, thin walls, light structural members, exterior columns and beams	Reinforced reservoirs, water tanks, pressure pipes, sewers, canal linings, dams of thin sections	Heavy walls, piers, foundations, dams of heavy sections
Extreme:			
1. In severe climates like northern U. S., exposure to alternate wetting and drying, freezing and thawing, as at the water line in hydraulic structures	5½	6½	6
2. Exposure to sea and strong sulphate waters in both severe and moderate climates	0.73	0.73	0.80
Severe:			
3. In severe climates like northern U. S., exposure to rain and snow, and freezing and thawing, but not continuously in contact with water	6	6	6¾
4. In moderate climates like southern U. S., exposure to alternate wetting and drying, as at water line in hydraulic structures	0.80	0.80	0.90
Moderate:			
5. In climates like southern U. S., exposure to ordinary weather, but not continuously in contact with water	6¾	6	7½
6. Concrete completely submerged, but protected from freezing	0.90	0.80	1.00
Protected:			
7. Ordinary inclosed structural members; concrete below the ground and subject to action of corrosive groundwaters or freezing and thawing	7½ 1.00	6 0.80	8¼ 1.10

[1] Surface moisture carried by the aggregate is included as part of the mixing water.

method is so simple, so easy to specify definitely, and so convenient to inspect properly, that it is certain to remain a favorite method for small jobs.

TABLE 4-2.—EMPIRICAL PROPORTIONS FOR CONCRETE

Kind of work	Proportions		
	Lean	Rich	Average
Mass concrete, heavy pavement bases, etc.	1:3:6	1:2:4	1:3:5
Reinforced-concrete structures and thin bases	1:2½:5	1:2:3	1:2½:4
Pavements, sidewalks, curbs, etc.	1:2½:4	1:1:1½	1:2:3* 1:2:3½†

* Hand compacted.
† Machine compacted.

Adjusting Proportions of Ready-mixed Aggregates.—Occasionally it is convenient to use bank-run gravel or the so-called *concrete mixes* of certain commercial pits. These materials usually carry an excess of sand and, therefore, the proportions should be readjusted. This is usually done by increasing the cement until the cement-sand ratio set by the specifications is obtained.

The mixed aggregate is separated into sand and rock by means of a ¼-in. screen and the number of parts of each obtained from 100 parts of the original gravel determined. By multiplying the number of parts of sand in the aggregate by the required cement-sand ratio as given in the specifications, the number of parts of cement per 100 parts of original gravel is obtained and is reduced to a unit of cement as a basis. In the same way the proportion of rock present may be determined and the deficiency computed.

Example.—Assume that the specifications call for 1:3:5 concrete and 100 parts of bank-run gravel yields 60 parts sand and 45 parts rock.[1]

Parts of cement required per 100 parts gravel $= \frac{1}{3} \times 60 = 20$

Ratio of cement to gravel $= 20 : 100 = 1:5$

Thus a 1:5 mix of the given gravel is required to give a concrete with an equivalent cement-sand ratio.

The cement-rock ratio is $20{:}45 = 1{:}2\frac{1}{4}$. Therefore the adjusted mixture is actually a 1:3:2¼ concrete. It is evident that the addition of 2¾ parts of screened rock would complete the specifications. Therefore, a 1:5:2¾ mixture using the bank-run gravel and screened stone will give a 1:3:5 concrete.

[1] The sum is always more than 100.

Consistency.—The consistency of the concrete is of extreme importance not only on account of its relation to the ease and effectiveness of placing and finishing but on account of its marked effect on the strength and porosity of the hardened concrete.

Figure 4-1 shows a typical water-strength curve. The crest of the curve occurs when the consistency is such that after considerable tamping water barely flushes to the surface, and the concrete becomes stiffly jelly-like. This point corresponds closely with that of maximum density. On the left of the crest the concrete is dry and sandy and is harsh and difficult to compact and finish. To the right of the crest the concrete becomes increasingly plastic, then soupy and finally a point is reached

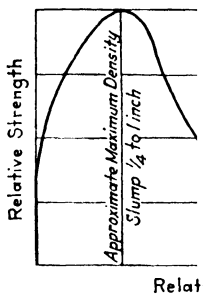


FIG. 4-1.—The effect of water content on the strength of concrete.

beyond which no more water can be retained in the setting concrete, the cement and aggregates settling out, leaving clear water on top. This water must be drained off, evaporated, or be reabsorbed by the setting concrete before the surface can be finished. Moreover, this settling action frequently brings to the top, especially if the concrete is stirred or tamped, the laitance from the cement and the silt from the aggregate which forms a layer of inert material that never hardens and which scales off later if exposed or forms a *mud seam* if more concrete is placed on top.

As previously stated, the dry mixtures cannot be well finished. Similarly, the very wet mixtures cannot be properly finished. The soupy mixture of cement and water runs out, washing the sand away from the rock, and thus causes the well-known *segregation of materials*. In this condition, the concrete cannot be floated or troweled and has the appearance of being deficient in mortar. Many contractors complain that the concrete will not finish and beg the engineer for "more fine stuff" when absolutely

the only difficulty is an excess of mixing water. As the water is reduced the cement becomes pasty and forms with the sand a sticky mortar which completely covers the coarse aggregate so that the entire mass is plastic and can be worked into place. Under the float, trowel, or light tamping, a smooth working mortar which is easily finished is brought to the top.

From the foregoing it is evident that, for the sake of ease and effectiveness of placing and finishing, the water content should be to the right of the crest of the curve in Fig. 4-1 but at the same time as near the crest as possible in order to obtain the greatest strength. If conditions demand a soft consistency it can be obtained only at the sacrifice of strength, and if the strength

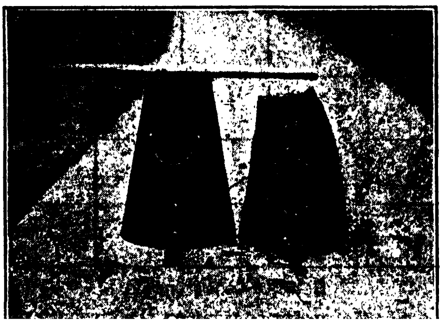


FIG. 4-2.—Slump test.

must be maintained it can be done only by using additional cement. Proportioning and consistency are therefore absolutely inseparable.

Measures of Consistency.—Many attempts have been made to devise a measure of consistency but so far with only partial success. Different cements form mortars of different behavior. Different aggregates act differently. Temperature and perhaps other factors have an effect which taken together makes the problem of a universal measure of consistency well-nigh impossible.

The *flow table* (A.S.T.M. C39-33) is a laboratory device that gives fairly consistent results within the range of plastic mixes but breaks down for very wet or very dry mixes. The *slump test* (A.S.T.M. D138-32T) has the same limitations and is somewhat less consistent in its results but is usable in the field. The test is made by filling a conical metal form 4 in. in diameter at the top, 8 in. in diameter at the bottom, and 12 in. deep with the concrete by tamping in successive batches and then carefully

removing the form and measuring the settlement or *slump* of the released pile (Fig. 4-2).

Slumps up to about 7 or possibly 8 in. are fairly indicative of the consistency. Beyond this the concrete is becoming sloppy instead of plastic and the slump is affected by the tendency of the mortar to run out and by the natural piling of the coarse aggregate, and the test becomes unreliable. Although not a perfect measure of consistency, it is a useful device and at least possesses the merit of permitting a definite specification to be written.

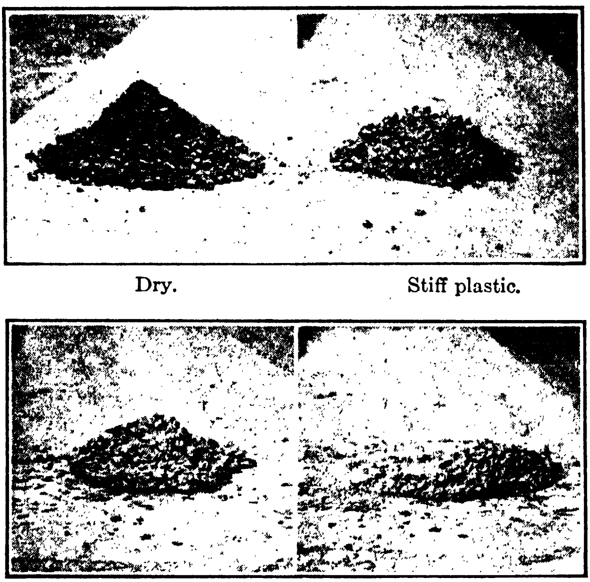
Water-cement Ratio.—The water-cement ratio forms a convenient method of indicating or specifying the amount of water. As previously defined, the water-cement ratio is the ratio of the

TABLE 4-3.—APPROXIMATE SLUMPS FOR DIFFERENT WORK

Kind of work	Character of concrete	Slump
Concrete blocks, etc., where forms are immediately removed and no distortion is permitted	Sandy, granular surface with only slight moisture after heavy tamping. High strength	0
Curbs, etc., where forms are removed at once. Slight deformation permissible	Slightly quaking, mortar flushes against forms after repeated tamping. Maximum strength	0 to ½
Machine-compacted pavements, etc.	Stiff plastic, jelly-like, with mortar flushing to surface. Very high strength	½ to 2
Hand-compacted pavements, etc.	Plastic, free-working mortar flushing out. High strength	1 to 4
Form work, simple reinforcing. Puddled rather than tamped	Soft plastic, moderate strength	3 to 6
Complicated reinforcing, puddled	Very soft plastic, flows but not soupy. Fair strength	4 to 7
Spouting distribution, puddled	Flows readily, somewhat soupy. Low strength	6 to 9
None	Soupy, segregates. Poor strength	Materials segregate

volume of water in a batch to the bulk volume of cement in the same batch, considering 94 lb., or one bag, of cement to be 1 cu. ft. Thus a water-cement ratio of 1.0 means 1 cu. ft., or 7½ gal., of water to each bag of cement.

The water-cement ratio for the same consistency, or slump, varies somewhat with the character of the materials and considerably with the proportions. The richer mixes require less water, or a lower water ratio, than do the leaner mixes. For a slump of about 1 in. a 1:2:3 concrete may require a water-



Dry. Stiff plastic.

Soft plastic. Wet.

FIG. 4-3.—Relative consistency.

cement ratio of only 0.70 to 0.80, while a 1:2½:4 mix may require 0.90 to 1.00 and a 1:3:5 a value of 1.1 or more. These values may be used for a rough estimate but for any given conditions of aggregate, mixture, and desired consistency the water-cement ratio should be determined by trial.

After all, the consistency or, more correctly, the *workability* must be judged by the appearance and behavior of the concrete. The ability to do this can be completely gained only by observation and experience. Figure 4-3 will aid the beginner and may be of service to the more experienced.

Quantities of Materials.—The quantities of unmixed materials required for a given volume of concrete will vary with the proportions, the gradation of the aggregates, and the consistency. No table or calculation will, therefore, be exact under all conditions but within average conditions Table 4-4 is sufficiently accurate.

TABLE 4-4.—QUANTITIES OF MATERIALS FOR 1 CU. YD.* OF CONCRETE
(1 bbl. of cement = 4 cu. ft.)

Proportions by volume			Voids in rock							
			40 percent				50 percent			
Cement	Sand	Rock	Cement, barrels	Sand, cubic yards	Rock, cubic yards	Water,† gallons	Cement, barrels	Sand, cubic yards	Rock, cubic yards	Water, gallons†
1	1	0	4.88	0.72	....	146.4				
1	1½	0	3.87	0.86	....	116.1				
1	2	0	3.21	0.95	....	96.3				
1	2½	0	2.75	1.00	....	82.5				
1	3	0	2.39	1.06	....	71.7				
1	1	1	3.27	0.48	0.48	98.1	3.50	0.52	0.52	105.0
1	1	1½	2.87	0.42	0.64	86.1	3.08	0.46	0.68	92.4
1	1	2	2.52	0.37	0.75	75.6	2.74	0.41	0.81	82.2
1	1½	2	2.22	0.49	0.66	63.6	2.39	0.53	0.71	71.7
1	1½	2½	2.01	0.45	0.74	60.3	2.18	0.48	0.81	65.4
1	1½	3	1.83	0.41	0.81	51.9	2.01	0.45	0.89	60.3
1	2	3	1.67	0.50	0.74	50.1	1.81	0.54	0.80	54.3
1	2	3½	1.54	0.46	0.81	46.2	1.69	0.50	0.88	50.7
1	2	4	1.44	0.43	0.85	43.2	1.58	0.47	0.94	46.4
1	2½	4	1.33	0.49	0.79	39.9	1.46	0.54	0.87	43.8
1	2½	5	1.18	0.44	0.87	35.4	1.31	0.48	0.97	39.3
1	3	5	1.11	0.49	0.82	33.3	1.22	0.54	0.90	36.6
1	3	6	1.01	0.45	0.90	30.3	1.11	0.49	0.99	33.3

* Actual yield will vary slightly with changes in consistency and gradation of aggregate.
† Amount of water for a water-cement ratio of 1.0. Multiply by the desired water-cement ratio to determine actual amount.

For the purpose of rough estimating, or for use when tables of quantities are not available, *Fuller's rule* is very convenient and easily remembered. It checks closely with Table 4-4 for 50 percent voids.

$$C = \frac{11}{c + s + g} \tag{4-1}$$

$$S = \frac{3.8}{27} \times Cs = 0.14Cs \tag{4-2}$$

$$G = \frac{3.8}{27} \times Cg = 0.14Cg \tag{4-3}$$

where C is the number of barrels of cement per cubic yard of concrete, S and G are cubic yards of sand and rock, respectively, per cubic yard of concrete, and c, s, and g are the proportions, respectively, of cement, sand, and rock in the mixture.

The amount of water required varies with the proportions and with the gradation of the aggregates and to a lesser degree with other factors. It must be remembered that only a slight increase in the water is required to increase the plasticity greatly. An increase of 10 to 20 percent in the amount of water is all that is likely to be required for even the softest consistencies permitted.

Measuring Materials.—The amount of materials for each batch of concrete must be measured in order to insure the proper proportions. The accuracy of the measurement must be in accordance with the magnitude of the work and the importance of maintaining a uniform mixture. In pavement work, each individual batch of concrete forms a definite part of the structure since there is no opportunity for the various batches to intermingle and lose their identity as in mass work. It is therefore very important that the measurement of the materials for pavements shall be done with unvarying accuracy.

The *cement* is best measured by the *bag* of 94 lb., net, in which it comes packed. Batches should always be based on a whole number of bags of cement as the unit, if this is at all possible. Frequently cement is shipped in bulk in which case some means of measuring is needed on the job. This may be done in any one of the ways used for aggregate but *weighing* is the most reliable. On small jobs with small mixers it is often necessary to split a bag, usually into halves. For this purpose an ordinary 16-qt. galvanized iron bucket is convenient, since when level full it will hold almost exactly a half-bag poured into it loose.

Aggregates may be measured with the shovel, the wheelbarrow, the measuring box, the measuring hopper, or by weight. *Shovel measurement* is used only with small mixers. The shovels should always be calibrated by measuring in a suitable box the number of shovelfuls of each material required in each batch. After this, with careful shovelmen, the batches can be measured within a range of 5 to 10 percent. On the other hand, it is very easy to mismeasure either accidentally or intentionally. No system of reasonable inspection can check each batch. Furthermore, if a little too much water is put in, it is very easy to add a shovelful or so of sand to correct the consistency.

Wheelbarrow measurement is convenient on building and bridge work with mixers of moderate size. The wheelbarrows should be calibrated with a measuring box after which it is very easy to maintain the measurement within 5 to 10 percent and at the same time get reasonably good inspection. Wheelbarrows can be obtained in capacities from 1½ to 4 cu. ft. but the 2½-cu. ft. size appears to be about the normal capacity for a man to handle and it lends itself reasonably well to most proportions and size of batches.

The *measuring box* is merely a box of known capacity. For checking other measuring devices a 1-ft. cube is frequently used, while for continuous measurement the dimensions of the box are such as to give the required amount for a batch. The boxes may be of either metal or wood. Usually the boxes are bottomless and are set in the wheelbarrow or the skip of the mixer. The materials are shoveled in, or run in by gravity and leveled, and then the box lifted off.

The *measuring hopper* is a modification of the measuring box, adapting it to larger capacities and direct loading. The hopper is placed so as to be filled by gravity from a bin. It is discharged by gravity into the mixer or the equipment used for transportation to the mixer. The size of the hopper is such as to give the required amount of material for a batch. Factory-built hoppers with suitable bins can be so arranged that one man can handle a battery of eight loading two trucks simultaneously with two batches each. They can be accurately adjusted to desired quantities and will measure different batches with a variation of less than 1.0 percent.

The *weighing* of the aggregates has largely superseded measurement by volume on highway work. The weighing equipment consists essentially of the measuring hoppers mounted on suitable scales. The desired weight of material for a batch is set on the scale beams and the hopper filled till it balances. The accuracy of the scales has been increased and refinements in the form of overload telltales and electric overload alarms have been added so that batches show a variation of perhaps less than 0.1 percent. This accuracy, combined with allowance for the moisture in the aggregate in measuring the water, results in concrete of very high uniformity. Scales have been developed for use with wheelbarrows so that the weighing of aggregates can be done on all kinds of small work as well as on large jobs.

Water may be measured with a bucket for small batches but large mixers are always equipped with a *measuring tank* which can be adjusted for different amounts and which operates with high accuracy.

Bulking.—Moist sand dropped into a container will occupy more space than will dry sand. This is known as *bulking*. Bulking increases with the moisture until the water content reaches about 5 percent and then falls off to practically zero when the sand is completely saturated. Fine sands bulk more than coarse well-graded sands. Furthermore, a moist sand dropped lightly into a small narrow container may bulk 20 percent or more, whereas the same sand dropped into large, wide containers with considerable force, as in actual construction work, may bulk not more than half as much. Coarse aggregates do not bulk appreciably.

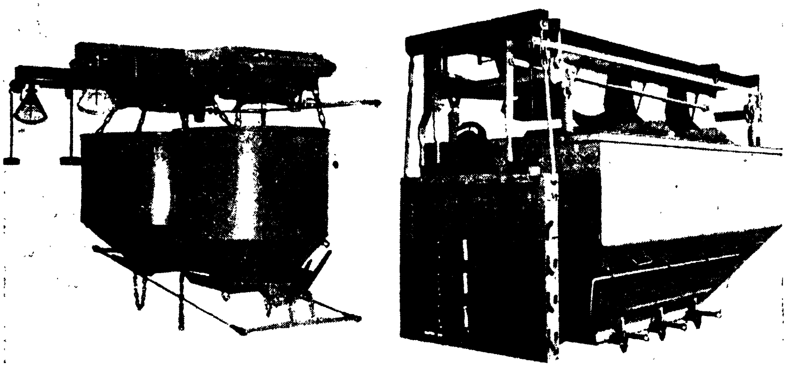


FIG. 4-4.—Weighing batchers for road construction. *A*, battery of two single-material hoppers equipped with over-under load telltales and alarms; *B*, unit batcher for three materials with over-under load alarms and interlocking controls.

It is evident, therefore, that bulking reduces the actual amount of fine aggregate in the concrete, and also that variations in the bulking due to differences in the moisture content cause variations in the actual proportions. The variations in bulking can be partly overcome by keeping the stock piles wet so as to maintain a constant moisture content. The effect of bulking may be nearly eliminated by weighing the materials. A small variation in the quantity per batch may still remain, due to variations in the moisture content. By making allowance for the moisture

in the aggregate, which can be readily done on the latest weighing hoppers, the effect of bulking and moisture changes are both eliminated.

Mixing.—To obtain good concrete it is essential that the materials be thoroughly mixed together. This mixing originally was done by hand but now a machine mixer of the batch type is universally used.

Occasionally, for small quantities or in case of emergency, *hand mixing* may be necessary. The rock necessary for a batch should be spread on a smooth impervious surface in a pile about 2 ft. wide and 4 in. thick. The sand should then be evenly distributed on top of the rock, and the cement on top of the sand. Two men with shovels then begin at one end of the pile and turn the mass, using small shovelfuls with a slicing motion to give the maximum stirring effect. After being turned the pile should have about the same dimensions as at first. Three or four turns should be made dry and then a crater formed in the middle of the pile and water added. Three or four turns, water being added after each as required, will be necessary to secure fair mixing and the proper consistency.

Mixers.—Machine mixers are on the market in a number of different designs and in various sizes to suit different classes of work. The mixing chamber or *drum* is made in several different shapes with or without internal blades but when mixers are properly designed and operated there appears to be little difference in their effectiveness.

Mixers are mounted on simple skids for use in fixed plants or on wheeled trucks with or without power drive or on caterpillar treads. For road work the last type is almost universally used since it is less destructive to the subgrade, requires less planking, and can be turned in a smaller space. These advantages more than offset the higher cost.

Power for Mixers.—Mixers are usually driven by electricity, steam, gasoline, or oil. In fixed plants where electric power service is available, electric power is perhaps the best since it is safe, convenient, economical, and requires very little attention. Steam engines were the standard for many years. They are simple, reliable, long-lived, and require little attention. The boiler is the troublesome part of the plant. The principal objection to steam is that an additional man is required to tend the boiler and engine. Extra time is involved in getting up

steam and shutting down, and the smoke is a nuisance, especially in cities.

For many years small mixers have been equipped with one- or two-cylinder gasoline engines with very satisfactory results. The largest mixers on roadwork are now equipped with gasoline engines, generally a four- or six-cylinder, high-speed, compact motor of the motor-truck type. These machines give remarkable service. With reasonable care during the working season and careful overhaul during the winter, the life compares favorably with the steam outfit. In use they are more convenient, since no additional men and no extra time are required to start and shut down, and the smoke nuisance is absent. Diesel oil engines are also being adapted to mixers.

Charging Mixers.—Small mixers may be charged by shoveling directly into the drum. Larger portable mixers are equipped with a *skip* in which the materials are placed and then hoisted so as to flow into the drum. In fixed plants the measuring hoppers usually discharge through spouts directly into the drum.

Water should always be admitted with the other materials. If the dry materials are run in first, the cement sticks to the wet surface of the drum and blades and soon cakes. If an excess of water is present the cement is likely to *ball up* before it is mixed with the aggregate. Each mixer has more or less individuality in this respect and, therefore, some attention should be given to the best way of charging and admitting the water.

Capacity of Mixers.—Manufacturers rate the capacity of mixers by the number of cubic feet of mixed concrete, assumed to be a 1:2:4 mix, which the mixer will deliver at a batch. The capacity is indicated by the size number and the loading position by a letter; thus, 21-E indicates an end-loading machine of 21 cu. ft. capacity. On the job, especially on road work, mixers are rated by the number of bags of cement handled in each batch. Table 4-5 gives the capacity of standard sizes of mixers. Larger sizes are made as specials.

Time of Mixing.—The strength of concrete and also its working qualities increase with an increase in the time of mixing. The increase during the first minute is very marked and then gradually falls off until beyond 2 to 5 min. the increase is not large. The *economical time of mix* is about 1 min. and this is the standard requirement of all road specifications. There is no great objection to mixing longer but it is essential that each batch

receive at least 1 min. of mixing. The *batch meter* is a device attached to a mixer which so interlocks the charging and discharging mechanisms that a batch once admitted cannot be discharged until it has been mixed the required time and a new batch cannot be admitted until the old one is discharged. The batch meter is required under the better specifications for paving work.

TABLE 4-5.—CAPACITY OF MIXERS

Proportions	Size of batch in bags of cement									
	Construction mixers							Road mixers		
	3½-S	5-S	7-S	10-S	14-S	21-S	28-S	10-E	13-E	27-E
1:1½:3	1	1	2	3	4	6	8	2	4	7
1:1½:3½	½	1	1	2	3	5	7	2	3	7
1:2:3	½	1	1	2	3	5	7	2	3	7
1:1¾:3½	½	1	1	2	3	5	7	2	3	6
1:2:3½	½	1	1	2	3	5	7	2	3	6
1:2:4	½	1	1	2	3	4	6	2	3	6
1:2½:4	½	1	1	2	3	4	6	2	3	5
1:2:5	½	½	1	2	2	4	6	1	2	5
1:2½:5	½	½	1	1	2	4	5	1	2	5
1:3:5	½	½	1	1	2	3	5	1	2	4
1:3:6	½	½	1	1	2	3	4	1	2	4

Placing.—The mixed concrete is discharged from the drum directly into the equipment which is to transport it to its place in the structure. In bridge and building work, wheelbarrows and buggies are common or the concrete is elevated to the top of a tower and permitted to flow by gravity through a system of spouts to its place in the forms. With a central mixing plant, the concrete is discharged into trucks or industrial railway cars for transportation to the job. Traveling mixers on paving work may be equipped with a long, swinging discharge spout to distribute the concrete over the subgrade or more frequently with *boom and bucket.* The concrete is discharged into a bucket which is suspended from a trolley on a swinging boom in such a manner that it can be run out to any point and dumped. After being dumped the concrete must be spread to the desired place. This is usually done with shovels.

Compacting.—All concrete needs a certain amount of compacting. Dry or stiff concrete must be thoroughly compacted. Plastic concrete is usually so soft as to require little actual compacting but it must be made to fill the forms completely. *Spading* is the process of forcing the aggregate back from the form so that the mortar can come in contact with the form, thus giving a smooth surface free from stone pockets. For this purpose the old-fashioned spade was originally used but now a special tool is available. *Puddling* is the stirring of the concrete in the form for the same purpose. It can be done with a steel rod or a large paddle made from a piece of 1- by 4-in. lumber.

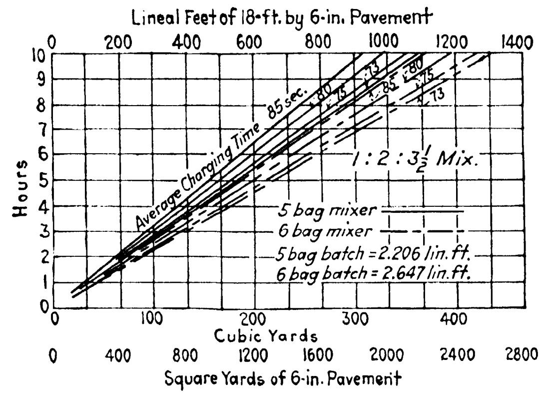


FIG. 4-5.—Output of five-bag and six-bag mixers.

Tamping consists of striking or pounding the surface of the concrete. The tamping tool may range from a light small-faced metal tamper to the heavy strike board used in hand compacting concrete pavements. *Compressing* consists of applying pressure to the surface generally with a rubbing motion. This is the action of the finishing machines used on road construction. *Vibrating* is a rapid shaking of the concrete or the form. Electrical or mechanical vibrators may be attached to the forms, operated on the surface of the concrete, or inserted into the mass of concrete. Vibrating is a very effective method of compacting and making the concrete properly fill the forms.

Finishing.—The exposed surfaces must be finished for the sake of shape and appearance. In form work, the surfaces against the forms are finished by contact with the form. After the forms are removed irregularities and form marks may be removed by rubbing with carborundum brick. Top surfaces

are struck off to shape and then finished with the float, belt, or trowel. The float and belt leave a granular surface while the metal trowel leaves a smooth glazed surface. Which to use is a matter of preference or of suitability to the particular kind of work. The various methods of finishing adapted to paving work are described in Chap. 9.

Curing.—Portland cement, in order to set and harden, must have a certain amount of water throughout the hardening period. The necessary water is mixed with the concrete and, therefore, the essential process of curing is the prevention of the escape of the water that is already present. Any means which will effectively retain the necessary water in the concrete for the necessary length of time can be used for curing.

The amount of water required for the hydration of the cement is only about 10 percent of its weight, while the amount of mixing water is several times this. Therefore it is not necessary that all the water be retained but that the evaporation be sufficiently retarded to keep the necessary water in the concrete. Walls, girders, columns, etc., can be effectively cured by leaving the forms in place. Floor slabs, sidewalks, pavements, etc., with a large amount of exposed surface in proportion to the volume of concrete, need special protection. The various methods adapted to paving work are described in Chap. 9 and these same methods may be employed for sidewalks, floors, etc.

The length of curing time is a function of the needs of the work and the temperature. Concrete gains a very large part of its strength in the first 28 days and therefore the strength at this age is the one usually employed in designing. The method of curing must, therefore, be such that the concrete will gain its proper strength in this length of time. In buildings, etc., where the full load does not come on the concrete immediately, forms may be removed earlier than 28 days, the retarded evaporation being sufficient for the remainder of the time. On pavements the full load is likely to come immediately after opening to traffic; therefore, ample curing time must be given. When the time of curing is of necessity short, richer mixes or fast-hardening cement must be used.

The normal curing time of 28 days is based on a temperature of about 70°F. If the temperature is warmer, curing is more rapid and the time may be reduced. If colder, more time is required. Tests indicate that concrete requires about one-half

as much time at 90° and twice as much time at 40° as at 70° to gain the same strength. It gains practically no strength while frozen, even though it may not have been injured by freezing while setting. The curing time should, therefore, be adjusted to the climatic conditions.

The actual curing time necessary for any particular job may be determined by means of a series of test specimens. These samples are cast from the concrete being used while the main

FIG. 4-6.—Molding test beams for determining the curing time for a concrete pavement. Note the side forms and the scratch template for checking the subgrade immediately behind the mixer.

structure is being poured. They are cured as nearly as possible in the same manner as the structure. From time to time specimens are tested and when they show a strength adequate for the given conditions the work may be put into service. This method can be used wherever facilities for making the necessary tests are available. It is accurate and takes into consideration all of the factors which may affect the curing time.

Concrete in Cold Weather.—Concrete for nearly every purpose except pavement can be successfully placed in cold weather if proper care is taken. First of all, the materials must be well above the freezing point. They may be heated by direct fire or by steam but care must be taken not to overheat them as this may cause a *flash set* in the cement in contact with the rock which is later broken by the placing and finishing. Antifreeze compounds may be employed. Of these common salt and calcium chloride are the most common. They are dissolved

in the mixing water up to about 5 percent by weight of the cement. This will serve to lower the freezing point perhaps 5°F. Calcium chloride also acts as an accelerator speeding up the setting of the cement.

After being placed, the concrete must be protected from freezing for a period of at least 5 days, or until the cement has gained some strength. If permitted to freeze too soon, the free water collects about the particles of aggregate and the pressure set up as it freezes disrupts the bond of the cement and the concrete crumbles to pieces when it thaws out. After several days the freezing will not have this disruptive effect but the cement does not harden while frozen; hence ample time must be allowed after the concrete has thawed before supports are removed. The concrete may be protected by maintaining the structure above the freezing point by artificial heat or by so covering it that the radiation of the heat it contains will be sufficiently slow. Wood forms act as lagging, and exposed surfaces may be covered with straw or manure.

Pavements and sidewalks, etc., should never be laid when the ground is frozen and the temperature is low because it is impossible to protect the concrete from freezing. Frequently concrete may be laid during the day but the night temperature is low enough to freeze a thin layer of the surface which later scales off. This can be prevented by a covering of canvas, straw, or manure.

Forms.—All concrete is molded to shape in *forms* of some kind. Buildings, bridges, culverts, etc., call for rather elaborate forms so placed as to mold and support the concrete until it has set. These forms are usually made of wood but metal may be used if the number of times each unit of the form is used is sufficient to warrant the added cost, or where metal only will lend itself to the desired shape.

The work of building forms is an art in itself. Surfaced lumber is used so as to give a smooth surface; but if the proper consistency is used, matched edges are not necessary. The forms must be braced to hold them in position and sufficiently tied together so that they will not bulge or open up owing to the pressure of the concrete. It must be remembered that concrete weighs about 150 lb. per cubic foot and, if very soft, may give a hydrostatic pressure as much as twice that of water.

Pavements, sidewalks, curbs, etc., require less form work. The subgrade acts as a bottom form and is the permanent sup-

port. The sides are then the only portions requiring forms. On city pavements the curbs are generally placed first, using wooden or metal forms and then the pavement is laid using the curbs as side forms. On rural roads where no curb is used, side forms are required. These are usually of steel and necessarily so if a finishing machine is used (see Fig. 4-6).

The top surface of all concrete structures is normally *finished* instead of being molded by means of a form, although in a few cases the forms may completely enclose the concrete.

Problems

4-1. Compute the net quantities of materials for 12,000 sq. yd. of 8-in. concrete pavement if the proportions are 1:2:3½, the rock contains 50 percent voids, and the water-cement ratio is 0.8. Use Table 4-4 and check by Fuller's rule. How many carloads of each material except water?

4-2. Cement is $1.70 per barrel on the siding, rock and sand are 72 cts. per ton at the pit, the freight rate is 64 cts., the unloading and hauling of the aggregates is 40 cts. per cubic yard and 5 cts. per bag for cement, water is 20 cts. per 1,000 gal. Compute the cost of the materials in Prob. 4-1.

4-3. If the average rate of evaporation is ⅜ in. per day, what will be the amount of water required to cure the pavement in Prob. 4-1 by the ponding method (Chap. 9) for a period of 12 days? How does this compare with the amount of mixing water?

4-4. A concrete sidewalk ½ mile long, 5 ft. wide, and 4 in. thick is to have a base course of 1:2¼:4 concrete and a top course of 1:2 mortar ¾ in. thick. Compute the quantities of materials, except water, from Table 4-4 using 40 percent voids.

4-5. What is the output of a 21-E mixer per 8-hr. day with a 1:2:3½ mix if the mixing time is 1 min. and 30 percent of the total time is required for charging, discharging, and lost time?

CHAPTER 5

DRAINAGE

Drainage is the process of removing excess water from the roadway, or of preventing excess water from reaching it. All soils become more or less soft when wet, which renders them unsuitable either as road surfaces or as subgrades. The excess water must, therefore, be removed or intercepted as quickly as possible to prevent undue softening. Furthermore, water standing on the surface of a road interferes with traffic and hence should be speedily removed or prevented from collecting.

Water reaches the roadway by direct precipitation, by surface flow from adjacent lands, by floods in streams, and by percolation through the soil. An adequate drainage system must make proper provision for the disposal of water from all of these sources. The water that falls on the earth in the forms of rain, snow, sleet, and hail is termed *precipitation.* It is the source of all the water to be drained away. Rain and snow are the forms of precipitation of primary importance in road work.

Rainfall.—Rain supplies the largest portion of the precipitation. The amount of rainfall is measured in inches of depth over the given area. In order to prevent flood damage, a drainage system must remove the water nearly as fast as it falls; therefore, the *rate* of precipitation or *intensity of rainfall* is the fundamental factor in the design of storm drainage systems. The intensity of rainfall is measured in *inches* of depth *per hour.*

Storms vary greatly in extent, duration, amount of precipitation, and frequency of occurrence. Rainfalls of extremely high intensities cover comparatively small areas, are of relatively short duration, and normally occur infrequently. As the rate of precipitation decreases, the storms generally cover larger areas, last longer, and come oftener. Local areas of very high intensity of rainfall may, however, occur inside these larger storms.

For a given area it may therefore be said that on the average:

a. As the intensity increases the frequency decreases.

b. As the duration increases the intensity decreases.

c. The extremely high intensities are to be expected inside storms of greater size and moderate average intensity.

It is rarely economical to provide a drainage system which will care for the extremely heavy rainfalls of very rare occurrence. On the other hand, it is necessary to provide a system which will keep the damage due to flooding at a minimum and which can be constructed at a reasonable cost. In the business district of a city the property values are high and the damage from even a small flood is likely to be costly. Furthermore, the drainage characteristics of the area are well established and are not likely to change materially during the life of the system. Consequently, the drains should be designed for the heavier storms that are likely to occur perhaps once in 30 to 40 years or more. In residential areas in cities, and in villages, property values are lower and flood damage probably less, while the area may change in character in a few years. Therefore, it may be desirable to build drains only sufficient for the more moderate storms having a frequency of 15 to 25 years. Rural areas can generally be adequately served by providing for the milder storms occurring every 5 to 10 years. The engineer must use judgment in choosing the frequency to be considered in order to balance the cost of construction against probable flood damage during the period in which the system may be expected to serve without rebuilding or enlarging.

Estimating Rainfall.—Many formulas have been suggested for estimating the rainfall to be expected. All of these are empirical equations based on records of observed storms. Probably the most reliable of these, at least for the United States east of the Rocky Mountains, are those developed by Meyer[1] since they are based on a careful correlation of all recorded storms in that area. Meyer's formulas have the general form

$$i = \frac{c}{t + d} \tag{5-1}$$

in which i is the intensity of rainfall in inches per hour, t is the duration of this rainfall in minutes, and c and d are terms depending on the character and frequency of the storms. Table 5-1

[1] MEYER, ADOLPH F., "Elements of Hydrology," 2d ed., John Wiley & Sons, Inc., New York, 1928.

shows values of c and d for several groups of cities and various frequencies of storms.

To use Eq. 5-1, the desired frequency is chosen, the given location correlated with listed groups of cities, and the corresponding values of c and d taken from Table 5-1. This fixes the formula for the given location and frequency. Thus central Illinois correlates with Group 3 and for a 25-year frequency the equation becomes

$$i = \frac{181}{t + 21} \qquad (5\text{-}1a)$$

The duration t is usually taken as the *time of concentration* which is the length of time required for water from the most remote point of the given area to reach the outlet. The value of i corresponding to this value of t can be expected to give the maximum flow, since for a shorter time the entire area will not be contributing water, while for a longer time the expected intensity will be less. The time of concentration t is estimated from a knowledge of the topography and the character of the soil and is largely a matter of judgment and experience.

Runoff.—*Runoff* is the portion of the rainfall which flows away over the surface and hence is the amount of water for which the

TABLE 5-1.—VALUES OF c AND d IN MEYER'S FORMULA FOR INTENSITY OF RAINFALL

Frequency of storms, years	Group 1		Group 2		Group 3		Group 4		Group 5	
	c	d	c	d	c	d	c	d	c	d
5	220	27	171	23	122	18	108	17	90	13
10	276	32	214	26	150	19	132	19	105	13
25	355	40	252	28	181	21	160	20	126	14
50	450	50	289	30	216	23	186	21	152	16
100	600	65	325	32	256	25	210	22	180	18

Group 1.—Jacksonville, New Orleans, Galveston (Gulf Coast).

Group 2.—New York, Philadelphia, Washington, Norfolk, Raleigh, Savannah, Atlanta, Little Rock, Fort Worth, Abilene, Bentonville, St. Louis, Kansas City, Des Moines, Lincoln.

Group 3.—Boston, Albany, Pittsburgh, Elkins, Asheville, Knoxville, Memphis, Cairo, Indianapolis, Cincinnati, Cleveland, Detroit, Grand Haven, Chicago, Madison, St. Paul, Moorhead, Yankton, Dodge.

Group 4.—Rochester, Buffalo, Escanaba, Duluth.

Group 5.—Denver, Bismarck.

surface drains must be designed. It is affected primarily by the intensity of rainfall, the imperviousness of the soil, and the slopes of the ground. High rates of rainfall have high runoff since the larger volumes of water give higher velocities in the drainage channels, resulting in less time for percolation into the soil. Steep grades also increase the runoff by increasing the velocities of flow. Porous soils take up large amounts of water rapidly and thereby reduce the runoff. Tight soils and impervious coverings, such as pavements and buildings, increase the runoff.

The runoff is also affected by the temperature, the humidity, the area, and the condition of the soil. Warm weather tends to reduce the runoff by increasing evaporation, thus drying the soil so it will take up more water. High humidity retards evaporation. Large areas show lower runoff since there is more time and greater opportunity for percolation and evaporation. At the beginning of a storm the soil may be dry and hence take up water rapidly, but as the storm progresses the soil becomes more and more nearly saturated, thus reducing the amount and rate of percolation with a corresponding increase in runoff. Frozen soil, especially if frozen when well saturated, is highly impervious. The runoff from a given area may thus vary a great deal from time to time.

The *runoff factor* r is the term by which the intensity of rainfall is multiplied to obtain the rate of runoff. It is often expressed as the percentage of the rainfall. This factor is also sometimes called the *imperviousness factor*, since the amount of runoff must be the same as that refused by the soil.

In built-up business districts where the entire area is covered with buildings and pavements, the runoff factor will generally range from about 0.9 to nearly 1.0. Closely built-up residential or industrial areas may have a runoff factor from 0.5 to 0.9 depending upon soil and grades. Detached dwellings areas may have a factor of 0.3 to 0.5, while unimproved flat lands may have a factor as low as 0.1. The selection of a runoff factor for use in drainage design is a matter of judgment backed by experience and a knowledge of the particular area. It should be chosen for the condition or time of year when the runoff is likely to be the highest.

Ground Water.—The water which does not run off either evaporates or enters the soil. Part of the latter is retained by

capillary action, part is absorbed by vegetation, while the remainder percolates as free water under the action of gravity. This percolating water gradually flows toward the natural channels where it emerges and contributes to the stream flow. Part of it may be intercepted by artificial drains, thus contributing to the flow in the drainage system.

The amount of capillary water in a given soil tends to remain constant. Therefore, capillary action will draw water considerable distances above free-water level. Capillary water itself may not cause trouble but the amount may be so near the critical point that only a small addition of free water is required to soften the soil. There are a few soils, however, whose capillary action is so great and whose plasticity index is so low that they are actually softened by the capillary water.

Saturation occurs when the voids of the soil are filled with water. At some distance below the surface the ground water constantly saturates the soil, and the height of this surface of saturation is termed the *ground-water level* or *water table.* The water table fluctuates, rising even to the surface during prolonged rains but falling when the rain stops. Interference with the outlet such as floods in the stream or frozen banks will cause the water table to rise, while a free outlet will cause it to fall.

Surface Drainage.—The process of removing surface water is termed *surface drainage.* It is also often called *storm drainage* since the largest volume of water to be removed occurs in time of storm. A *storm drain* is one designed to carry storm water or surface water. If it is an underground conduit, it is often termed a *storm sewer,* especially in city work. A storm drain may also act as an underdrain, if of suitable type and favorably located.

The amount of water to be handled by the surface-drainage system at any point is the runoff from the drainage area above that point. If this area in acres is known it is evident that the quantity of water in cubic feet per second would be

$$\frac{A \times 43{,}560 \times i \times r}{60 \times 60 \times 12}$$

Since the numerical terms in the numerator and denominator are practically equal they may be canceled and we have the well-known equation

$$Q = A\,i\,r \tag{5-2}$$

in which Q is the runoff in cubic feet per second, A is the drainage area in acres, i is the intensity of rainfall in inches per hour, and r is the runoff factor.

The area A is determined from a contour map or field measurements, i is found from Eq. 5-1, and r is chosen as previously indicated.

Underdrainage.—The process of removing ground water or lowering the water table is termed *underdrainage* or *subdrainage.* Underdrainage does not drain off capillary water but, since the amount of capillary water decreases with the height above free water, a low water table reduces the amount of capillary water at the road surface. A small rainfall, therefore, causes less complete saturation of the soil and the subdrain by maintaining considerable head for the percolating water, increases its flow, and thus reduces the period of saturation at the surface.

The amount of water to be carried by the subdrain is hard to estimate. Experience has shown, however, that if the subdrain will remove a certain depth of free water from the entire area in 24 hr. no damage will result to crops. This same rate generally proves satisfactory for road purposes except in springy places which must be considered separately. The depth of water to be removed in 24 hr. is called the *drainage modulus* and typical values are given in Table 5-2. It is evident that $M = 24\ ir$, hence the relation between M and Q is given by the equation

$$Q = \frac{AM}{24} \tag{5-3}$$

The area A to be considered in this case is that which may be expected to contribute water to the drain by seepage. Porous tile form the best subdrains, and the range of influence of a single line of tile depends on the porosity of the soil and the depth of the tile below the surface. In average soil and for a depth of 4 to 5 ft. the range of influence may be taken as about 100 ft. on each side of the tile line. For loose soils this distance may be doubled, while in tight soils it may be reduced to 10 to 20 ft.

Open Ditches.—Open ditches are used primarily for surface drainage. Their function is to collect the surface water from the road and adjacent lands and convey it to natural outlets. Under some conditions open ditches may also serve as underdrains but

they should rarely be depended upon for this purpose. The cross-section of open ditches may vary from the broad, shallow side ditch of the well-designed rural road to the regular trapezoidal cross-section with flat bottom and relatively steep sides used for farm drainage ditches and stream channels. Open ditches are often a source of danger to traffic and, therefore, they should be so designed and located as to reduce this danger to the minimum.

TABLE 5-2.—COMMON VALUES OF THE DRAINAGE MODULUS

Annual rainfall, inches	Typical states	Drainage modulus, M in. per 24 hr.	Flow per acre, cubic feet per second
Under 30..........	Minnesota, Dakota, Kansas, Montana	¼	0.0105
30 to 40..........	Iowa, Wisconsin, Michigan, Illinois, Indiana, Ohio	⅜	0.0157
40 to 50..........	Arkansas, Mississippi, Louisiana, Tennessee, Carolina, Georgia	½	0.0210
Over 50..........	Florida, Washington	¾	0.0315

Tile Drains.—Tile drains are used both for subdrains and for outlets for surface water. For subdrainage work, concrete or unglazed clay tile with straight ends are generally used, although under certain conditions perforated metal pipe may be employed. City storm drains, sanitary sewers, etc., should be made of *sewer pipe, i.e.*, tile with interlocking ends (see Chap. 2). The joints may or may not be sealed as the conditions require.

Flow in Open Ditches.—The amount of water which any channel can carry is given by the equation

$$Q = av \tag{5-4}$$

in which Q is the capacity in cubic feet per second, a is the cross-section of the flowing water in square feet, and v is the velocity of flow in feet per second.

Manning's formula for the velocity of flow may be given in the form[1]

[1] The usual form is $\frac{1.486}{n}R^{2/3}S^{1/2}$ where S is the slope of the channel expressed as a decimal but since road plans always show the grades in percent the form given on p. 94 is preferable.

$$v = \frac{0.1486}{n} R^{2/3} G^{1/2} \tag{5-5}$$

in which n is the *coefficient of roughness* or *roughness factor*,[1] R is the hydraulic radius, and G is the grade of the tile line in percent. The hydraulic radius R is equal to the cross-sectional area of the flowing water in square feet a, divided by the *wetted perimeter* p of the channel in feet.

The roughness factor n has been determined experimentally for many kinds of channels. Well-shaped and well-maintained ditches in ordinary soils may have values as low as 0.025, but for ditches of the shape and condition common in road work a value of about 0.06 is much more probable. Using 0.0594, we have the simple form

For open road ditches:

$$v = 2.5 R^{2/3} G^{1/2} \tag{5-6}$$

Broad shallow side ditches lined with sod and weed stems may have velocities as low as one-half those given by Eq. 5-6. Such ditches, however, rarely carry large amounts of water and therefore are rarely designed on the basis of capacity. They are generally built to a standard cross-section for the sake of safety, appearance, and convenience in construction and maintenance.

Regular ditches for carrying water are trapezoidal in cross-section. The side slopes are such as will stand safely and the bottom widths sufficient to give the needed capacity with reasonable depth of water. With ditches of this shape there is no fixed relation between the hydraulic radius and other dimensions; hence the trial-and-error method is used in design. The amount of water to be carried is determined by Eq. 5-2 or 5-3. The size of the ditch is roughly estimated and trial dimensions chosen. The capacity of this tentative ditch is then determined by Eqs. 5-4 and 5-6 and compared with the amount of water the ditch must carry. If they do not agree, new dimensions are chosen and a second trial design made. This process is repeated until a satisfactory cross-section is found. In general, bottom widths are taken to the nearest foot, while the depth of water in small ditches may be taken to the nearest $\frac{1}{4}$ ft. Drainage engineers

[1] This n is the same as n in the Chezy-Kutter formula.

have prepared many diagrams and tables which greatly facilitate this work when much of it is to be done.

Flow in Tile.—Equations 5-4 and 5-5 apply to tile drains as well as to open ditches. Values of n as low as 0.010 have been found for well-laid tile and 0.012 is often used in design. In the author's opinion, sufficient allowance has not been made for the effect of laterals and especially in storm drains for the effect of inlets and catch basins. A value of n of about 0.015 seems more compatible with actual conditions in road and street drainage. Using such a value, we have from Eq. 5-5

For tile drains:

$$v = 10R^{2/3}G^{1/2} \tag{5-7}$$

Since tile are circular in cross-section,[1] it follows that when flowing full $R = \frac{1}{4}D$ where D is in feet. Substituting this in the foregoing equation, we have with sufficient accuracy

$$v = 4D^{2/3}G^{1/2} \tag{5-8}$$

Furthermore, there is a fixed relation between a and D; hence, combining Eq. 5-8 with Eq. 5-4, there results

$$Q = \pi D^{8/3}G^{1/2} \tag{5-9}$$

and

$$D = \left(\frac{Q}{\pi G^{1/2}}\right)^{3/8} \tag{5-10}$$

In designing a tile line, the amount of water to be carried is found from Eq. 5-2 or Eq. 5-3 and the required diameter in feet computed by Eq. 5-10, or the capacity of a tentative size determined from Eq. 5-9.

The diagram Fig. 5-1 has been constructed from the foregoing equations for the commercial sizes of tile which are given in inches of diameter. To determine the necessary size of tile with Q known from Eq. 5-2 or Eq. 5-3, the diagram is entered at the bottom with the percent of grade and the vertical line followed to its intersection with the horizontal line corresponding to Q as shown at the left. This point will lie between lines showing the tile size, and the nearest commercial size should be taken.

[1] Equations 5-7 and 5-8 also apply to *square* cross-sections of height and width D when flowing full, since $R = D^2/4D = \frac{1}{4}D$. Equations similar to Eqs. 5-9 and 5-10 can therefore be made for square conduits.

The velocity can be interpolated from the velocity lines, some allowance being made for using the smaller or larger size of tile indicated.

When the area and the drainage modulus are involved the right-hand scale of the diagram is used by reducing the given area and drainage modulus to equivalent area with $M = 1$.

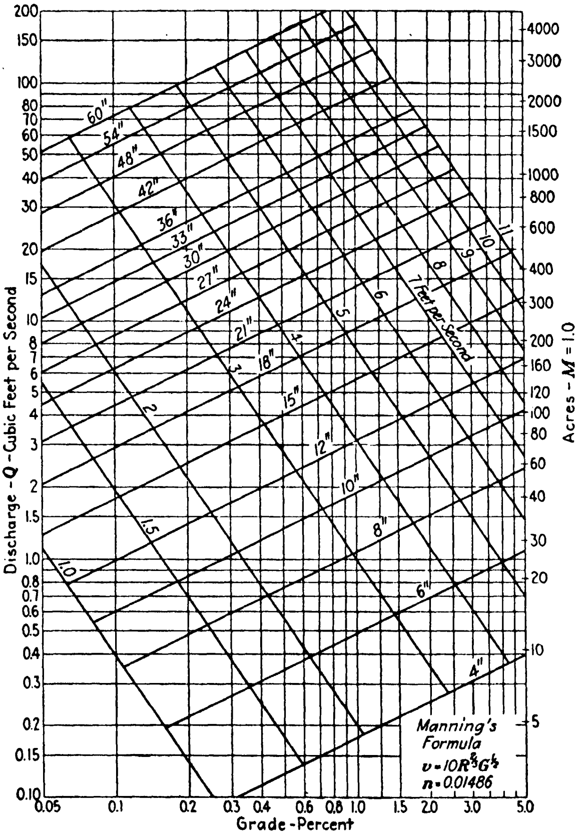


FIG. 5-1.—Capacity of tile drains.

Grades.—Grades for the tile lines should be such that adequate but not excessive velocities of flow are obtained. With velocities less than about 2 ft. per second there is danger of clogging the tile by the deposition of silt. Velocities greater than about 10 ft. per second are likely to cause damage to the tile or accessories by erosion. The minimum grade for the smaller sizes, therefore, is about 0.2 percent, but 0.3 percent is better. Larger sizes may

have flatter grades but difficulty is generally met in laying any size smaller than about 18 in. satisfactorily on a grade under about 0.2 per cent.

Open ditches of ordinary road size may be placed in grades as low as 0.05 percent, since they are readily accessible for cleaning. Maximum grades are limited by resulting velocities which will cause erosion of the banks. In ordinary soils the velocity should not exceed about 4 ft. per second. In extreme cases it may be necessary to line the ditches with concrete or riprap.

Streams.—Streams are the natural channels of water flow. They carry both surface water and water that reaches them by percolation. They are a component part of the road drainage system since they form the outlets of the artificial system. Ample provision must be made to carry them under the roadway by means of bridges or culverts, a process sometimes called *cross-drainage*.

Snow.—Snow occurs to a greater or less extent in many localities. Its bulk is much greater than that of water, the average ratio being about 8:1. When snow melts the released water must be handled by the drainage system. If the melting proceeds gradually, no unusual burden is placed on the drains. If, however, the melting occurs rapidly, as may occur under the influence of warm winds or coincident rains, the runoff may be considerable, especially if the soil is frozen or saturated. It may, therefore, be necessary to give consideration to snowfall in designing the drainage system in some localities.

Snow also offers impedance to vehicles and, if the fall is heavy, may entirely blockade traffic. *Snow removal* is the process of removing unmelted snow from the traveled way for the benefit of traffic. On rural roads the snow from the roadway is piled along the sides and therefore the drainage system must ultimately remove the water. In business districts the snow may be removed entirely from the street which also relieves the storm drains from carrying the snow water. In all snow-removal processes care must be taken not to obstruct the drainage channels with the packed snow.

DRAINING RURAL ROADS

The water to be drained from a rural road is surface water from the roadway, the roadside, and adjacent lands and ground water which might enter the roadway and soften the subgrade.

Crown.—The primary function of crown is to drain the water falling on the road surface, to the sides. Crown is exactly analogous to the roof slope of buildings. The amount of crown to be used depends on the kind of surface, convenience to traffic, and the appearance of the road. A smooth, hard surface requires less crown than a rough or soft one. Traffic desires little or no crown, but good appearance demands that there be at least a small amount.

During recent years there has been a marked reduction in the crowns used. Table 5-3 gives the desirable limits of rate of cross slope for different kinds of surfaces and also empirical equations for computing the total crown for different widths of roadway. These formulas should not be rigidly followed but should be employed merely as guides to the judgment. The resulting crowns agree well with present practice.

TABLE 5-3.—AMOUNT OF ROADWAY CROWN FOR RURAL ROADS OR CITY STREETS

Kind of surface	Desirable rate of cross slope, inches per foot		Desirable total crown C, inches, for total roadway width W, feet	
	Minimum	Maximum	W less than 40 ft.*	W more than 40 ft.†
Earth	¼	1	$C = W^2/133$	$C = \frac{1}{2}W - 9$
Gravel, Macadam	⅛	¾	$C = W^2/200$	$C = \frac{1}{3}W - 6$
Bituminous, Brick, Concrete, Stone block, Wood block	1/16	⅜	$C = W^2/400$	$C = \frac{1}{6}W - 3$

* Based on parabolas having crowns in a width of 20 ft. of 3, 2, and 1 in., respectively, for the three groups of surfaces.

† Based on crowns composed of the foregoing parabolas for a middle width of about 35 ft. and extended by straight slopes tangent to the parabolas. The crowns as determined by the equations may be laid out as simple parabolas with satisfactory results.

The crown is generally made parabolic in shape. Some engineers specify a circular crown and even compute the radius of curvature but this is wasted effort, since the difference between the circle and the parabola is infinitesimal and the parabola is much easier to compute and lay out.

On very wide roadways a parabolic crown which will not be too flat in the middle may be too steep at the sides. A hyperbolic crown has been suggested to overcome this difficulty, but its computations and layout are rather complicated. A simpler and entirely satisfactory method is to use a suitable parabola for the middle portion and straight slopes tangent to the parabola at the sides. These side sections need not be exactly tangent to the parabola but the break of slope should not be enough to spoil the appearance.

Side Ditches.—Present practice provides side ditches parallel with the roadway to collect the water discharged by the crown. The side ditch might well be called the eaves trough of the road.

FIG. 5-2.—The result of inadequate outlet for the side ditches.

It also collects the water from the roadside and from adjacent lands which slope toward the road.

Side ditches should never be any larger than necessary and should discharge into suitable outlets at the first opportunity. If water must be carried long distances, regular drainage ditches should be provided at a safe distance from the roadway or, preferably, tile drains of proper capacity with adequate inlets and free outlets should be installed.

For the sake of safety to traffic the side ditch should be broad and shallow. The minimum depth below crown of roadway should be about 1 ft. and the maximum depth should generally not exceed about 3 ft. The side slopes should be as flat as can be obtained. The slope toward the roadway should not be steeper than 3:1, while the back slope may be 2:1. Flat, well-

finished ditch slopes add greatly to the appearance of the road. The cross-section may be either V-shaped or trapezoidal since either can be easily constructed or maintained with the blade grader.

Side ditches may be placed on grades as flat as 0.1 percent, or even less. Steep grades may develop velocities of flow high enough to cause erosion. This may be controlled by baffle walls at suitable intervals. Such walls, if of a permanent type, are quite expensive and trouble with erosion may also develop from the water falling over them. It is therefore better and often cheaper to line the ditch with concrete or other suitable material or to provide a tile of sufficient size with frequent inlets to carry the bulk of the water. Sod is an effective preventive of erosion in ditches which have only occasional or small amounts of flow.

Intercepting Ditches.—Intercepting ditches are open ditches placed above the edges of cuts to intercept surface water from adjoining lands which otherwise would flow into the cut and perhaps erode the slopes or overload the regular side ditch. Such ditches should be placed far enough from the edge of cut to be free from the danger of being broken by caving of the cut slopes. They should be of ample capacity and have adequate outlets so they will not overflow and wash a channel to the cut. The regular trapezoidal ditch section with suitable side slopes is used.

Subdrainage by Open Ditches.—The attempt is sometimes made to use open ditches as underdrains. One of the principal arguments for the deep side ditch is that it will keep the water table below the road surface.

To be effective as an underdrain, an open ditch must be deep enough to reach well below the maximum desirable height of the water table. The effective depth, however, is only to the surface of free water in the ditch. During storms the water rises and consequently the ditch becomes decreasingly effective as an underdrain by the amount of the rise. Freezing of the banks makes them impervious and, therefore, ground water can enter the ditch only at or below water level. Increased head is necessary to overcome this resistance to discharge and therefore the water level in the soil rises. If flood flow occurs at the same time, the ditch is practically inoperative as a subdrain. Since this condition is likely to occur in the spring, when frozen ground causes high runoff and the thawing soil is releasing ground water, it is

seen that the open ditch is practically worthless as an underdrain at the very time underdrainage is most needed. A large ditch or stream, adjacent to a road, deep enough that the flood flow is always several feet below the crown of the road will, however, furnish underdrainage.

A side ditch deep enough to act as an underdrain will be expensive to construct and maintain. In addition it is a positive menace to the safety of traffic. Some authorities assert that there is no reason, with a well-built road, for vehicles to go into the ditch. This is perhaps true but the only type of "well-built road" which will even approximate this condition is one without soft shoulders and side ditches, *i.e.*, a city type of pavement with distinct curbs, but even on city streets vehicles have been known to jump the curb and land on the adjacent property.

Subdrainage with Tile.—The most effective method of underdrainage is by means of tile. If the tile system is designed for subdrainage only, the problem is exactly the same as farm drainage. If the adjacent farms are well underdrained, the road rarely needs it since the farm system will overlap the road.

The best location for a road drain is under the side ditch. It can be installed or repaired at any time without interruption of traffic and the depth of digging is less. If the soil is tight and underdrainage imperative, two lines, one under each ditch, are advisable. The depth of the tile should be from 3 to 5 ft. below the crown of road. Less depth will not lower the water table sufficiently and greater depth will act too sluggishly.

The 4-in. tile is the smallest used in farm drainage, but for road work a minimum of 6 or even 8 in. is advisable. The cost of laying is practically the same for these three sizes and the difference in the cost of the tile themselves is small. The larger sizes are more effective in collecting the ground water and are much less likely to become clogged. The need for still larger sizes should be determined by the methods outlined earlier in this chapter.

Backfilling.—Porous backfilling with cinders, gravel, broken stone, etc., is often practiced. It increases the collecting power of the tile and in effect forms a continuous inlet for surface water. Freezing may make porous backfilling temporarily inoperative as an inlet for surface water. Stone or gravel often silts up and becomes ineffective, while cinders, etc., that are intrinsically porous remain effective longer. Most agricultural soils and

many subsoils permit reasonable percolation and, therefore, porous backfilling is not required except in tight soil.

Surface Drainage with Tile.—Tile drains are sometimes used for surface drainage on rural roads. Their use will doubtless increase in the future. The demands for safer roads by the elimination of the open ditches and the necessity for wider pavements covering a greater portion of the right-of-way will require a drainage system both more efficient and occupying less space than the open-ditch system. On city streets tile drains form an indispensable part of the drainage system. The design of tile drains will, therefore, be considered in connection with city streets.

Farm tile systems can often be effectively used as aids in the surface drainage of the adjacent roads. Connections should be only to tile 8 in. or more in size. Well-designed inlets and adequate catch basins should be provided so that the water can enter readily and the tile not become clogged with silt and debris. With tile smaller than 15 in. it is desirable to use a trap between the catch basin and the tile to prevent the entry of floating drift. This use of the farm tile will not interfere with their normal function as subdrains, since the storm water will have entered and passed on before the maximum demand by seepage water is reached.

Seepages.—Seepages or springy areas are frequently met, especially in hilly country. Ground water flowing in porous strata between more impervious layers is tapped either by the road grading or by erosion. These spots occur mostly on the slopes below the crests of the hills. They can be cured only by adequate subdrainage so placed as to intercept the ground water. Flow from seepages may be continuous and, therefore, evident during grading. On the other hand, they may develop only in rainy weather and not be visible until after the road is completed. This latter kind is obviously the hardest to cure.

If the flow comes from one side, tending to cross the road, a single line of tile placed parallel with the road surface will usually serve the needs. Laterals may be advisable in some cases to pick up the water more quickly. If the flow is more nearly parallel with the road so that a longitudinal drain will not intercept it, underdrains must be placed in the road also. The best method is to carry a line along the side of the road in the usual way and tap diagonal drains, spaced 10 to 25 ft. apart, onto it.

The tile should be placed near the bottom of the porous stratum or, if not accessible, 2 to 5 ft. below the crown of the road. The mains should be not less than 8 in. and larger as required. The laterals may be 4 in. or larger, all of porous tile.

Blind Drains.—Blind drains, frequently called *French drains*, are sometimes used. They are made by digging trenches at the desired locations and filling them with cinders, gravel, broken stone, or other porous material. They are intended to collect ground water and convey it short distances, either to open ditches or to tile. Blind drains may be used for temporary work during construction, or in localities where tile are excessively expensive and stone or gravel cheap. Blind drains should never be substituted for tile unless the price of the latter is prohibitive.

Such drains are frequently placed along the edges of pavement slabs, and across the shoulders to the side ditches. Frequently, the shoulder sections silt up and render the system ineffective. Sometimes such so-called drains only aggravate the situation by collecting and holding water just where it is not wanted.

Surface vs. Underdrainage.—Rapid and complete surface drainage is absolutely essential to successful road building. If the entire road system and all seasons of the year are taken into consideration it is far more important than subdrainage. More roads are damaged, become unusable, or lose efficiency from inadequate surface drainage than from any other one cause. Imperfect surface drainage is the greatest defect in modern road building.

Underdrainage is restricted in its application. Many localities do not require it. Other places find it absolutely necessary but in both cases surface drainage is indispensable. Often better surface drainage of the road and adjacent territory will reduce the apparent necessity for underdrainage. The conclusion, therefore, is that *surface drainage is fundamental* and must first be provided, after which underdrainage should be added where conditions make it necessary or desirable.

DRAINAGE OF CITY STREETS

The storm drains of a city must carry the entire runoff including that from roofs, pavements, and open ground. The pavements cover a considerable area and, being practically impervious, deliver a high runoff which concentrates rapidly. Since flooding

of the streets interferes seriously with both vehicular and pedestrian traffic, it is imperative that the surface water be drained quickly.

Unpaved streets have a lower runoff than paved streets. Sometimes they can be drained by open ditches but difficulties at intersections, driveways, etc., usually result in constructing storm sewers.

Roof water collects rapidly and augments the surface flow. In business districts practically the entire area may be covered with roofs, sidewalks, and pavements, with resulting heavy runoff. In residence districts the roof water is less, and with more open

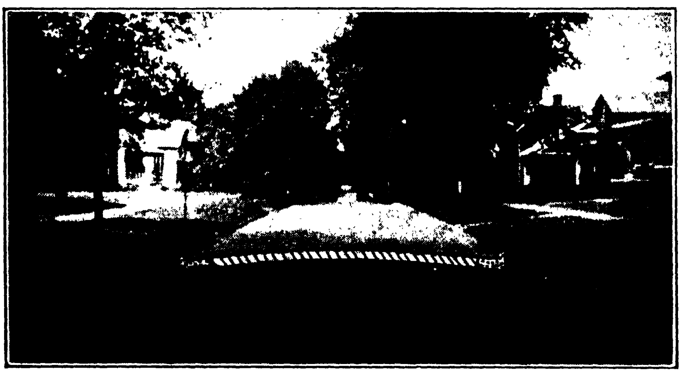


FIG. 5-3.—Typical cross section of a residential street.

ground the total runoff is lower. Outlying districts may have very low runoff but such districts are likely to develop into residence or business districts at anytime; hence their potential runoff as such must be considered in designing the system.

Drainage Facilities.—The visible provisions for surface drainage are the *crown*, the *gutters*, and the *inlets*. The invisible parts are the *catch basins* and *storm drains*, often termed *storm sewers*. Stream crossings requiring culverts or bridges, of course, may exist. These are treated under their respective subjects.

The normal cross-section of a residential street is shown in Fig. 5-3, whence it is evident that, in addition to the water on the pavement itself, the surface drains must take care also of the water falling between property lines and curbs which may or may not be covered with sidewalks and also the water from adjoining property except roofs. The roof water is normally carried directly to the storm drain by means of *house connections*.

Crown.—The amount of crown to be used on city streets is essentially the same as that used on rural roads with the same type of surface. Suitable values are shown in Table 5-3. The width to be considered in determining the crown is that between face of curbs where plain curbs are used or between edges of gutters where a special gutter structure, such as the combined curb and gutter, is used.

If a streetcar track is to be placed in the pavement the width occupied by the track should be deducted from the total width before the crown is computed. The width to allow may be 5 to 7 ft. Thus a 36-ft. pavement with a single track should have its crown computed on the basis of a width of about 30 ft. If more than one track is laid the width to deduct is about 5 ft. plus the distance between the center lines of the outside tracks. This deduction must be made because the crown is concentrated between the rails and the curb since the track must be practically level, and if the crown is not reduced accordingly the cross slope is excessive.

Gutters.—The gutter is generally formed by the slope of the crown and the curb. Ordinarily the water flow is restricted to a narrow space of indefinite width adjacent to the curb. Flood flow will require greater gutter capacity and the water will spread toward the middle of the pavement as it increases in depth. The height of curb should therefore be not less than the amount of crown in order to provide full gutter capacity.

The bottom of the gutter may or may not be of the same material as the pavement. Concrete, brick, stone block, and similar pavements form satisfactory gutters themselves. Bituminous pavements tend to disintegrate when covered with water and debris; hence the gutters are generally made of brick, stone, or concrete. Gravel and macadam may require paved gutters to prevent erosion. One of the favorite types is the combined concrete curb and gutter which unites the curb and a gutter slab in one monolithic concrete structure. Details of curbs and gutters are given in Chap. 12.

The grade of the gutter must be sufficient to carry the water away. If the pavement itself forms the bottom of the gutter, it is nearly impossible to build one that will not have pockets holding water on grades under 0.3 percent. The combined concrete curb gutter, however, has been satisfactorily laid on a

0.12 percent grade but normally a minimum of 0.2 percent is desirable.

If topography does not permit a general grade of the street on at least the minimum slope, the top of curb may be placed to the available grade and the gutter slope obtained by installing inlets at frequent intervals and sloping the gutters to them. This results in a variable height of curb. To avoid excessive variation in curb height and also to obtain suitable gutter slopes, the inlets should be not more than about 200 ft. apart.

Inlets.—Inlets are the openings from the gutters into the storm drains. They must be placed close enough together, and at such locations, and be of sufficient capacity to discharge the maximum gutter flow into the sewers promptly. They must be of sufficient

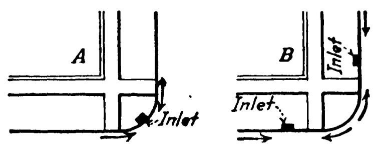


FIG. 5-4.—Position of inlets at curb corner.

strength to resist breakage and so designed as to prevent clogging by leaves and debris.

Inlets must be placed at all sags in the grade line. The capacity of an inlet is difficult to estimate but, on account of the danger of clogging, inlets should never be placed more than about 400 ft. apart. If a long stretch of pavement drains into a sag from both directions, double or even triple inlets should be placed.

On long grades intercepting inlets should be placed at intervals. Normal rains will be intercepted but in heavy rains the water is likely to have sufficient velocity for a large amount to run past the inlet unless the gutter is sufficiently depressed at the inlet to overcome this tendency. Care must be taken, however, not to make such a depression objectionable to traffic. See Chap. 12 and Fig. 12-12.

Inlets are normally placed at street intersections. Some engineers prefer a single inlet at the apex of the corner, while others place them back of the property lines as shown at *A* and *B*, respectively, in Fig. 5-4. The latter system frequently requires more inlets than the former and is, therefore, more expensive. As far as drainage is concerned there is little choice between the two systems, the primary consideration being the layout of the intersections as to sidewalks, grades, and cost.

With either system, inlets should be placed whenever the gutter grades are toward the intersection. Figure 5-5 shows the cases which may arise. There is often a tendency to omit the inlet when the flow turns a corner. This concentrates the water at the next corner. If the same thing is repeated at the succeeding corners it may result in the flow from the entire perimeter of the block being concentrated at one corner, which is obviously highly objectionable. Perhaps the greatest defect of most street drainage is the lack of a sufficient number of well-designed and properly located inlets. The number, size, type, and location

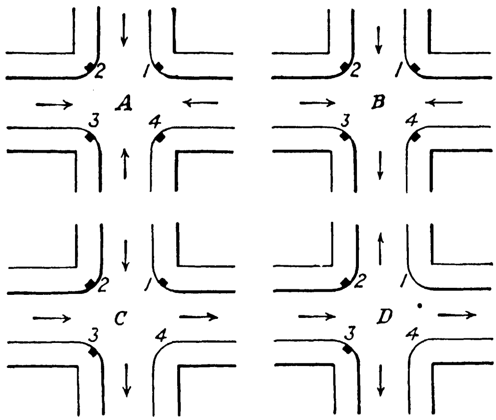


FIG. 5-5.—Location of inlets with respect to grades.

of inlets should receive careful attention since adequate surface drainage is of utmost importance.

Catch Basins.—All inlets, except those connecting to a drain larger than about 42 in. should discharge into the tile through a *catch basin* or sedimentation chamber. The catch basin may be placed at any convenient point between the inlet and the drain. When catch basins are placed directly in the tile line they may also become *manholes*, since they can be made to provide access to the drain for cleaning and inspection. In some cities the storm water and the sanitary sewage are carried in the same conduit known as a *combined sewer*. In this case the manholes must have smooth channels through them so that sewage will not lodge and putrefy; consequently, the catch basins must be separate structures.

Catch basins may be placed at each inlet or a single catch basin placed at an intersection and all the inlets connected to it

by tile as indicated in Fig. 5-6. The first system has a slight advantage over the second in that there is greater silt capacity, less tile, and easier access to the tile. Its principal disadvantage is greater cost.

Line, Grade, and Manholes.—Storm drains smaller than about 42 in. should be laid to straight line and grade between manholes. The manholes should be placed at every change of direction or grade, at every major junction, and not more than 600 ft. apart on tangents. In case of clogging, etc., the trouble can be readily located and the tile cleaned from the manholes. Without manholes and straight alinement, trouble is hard to

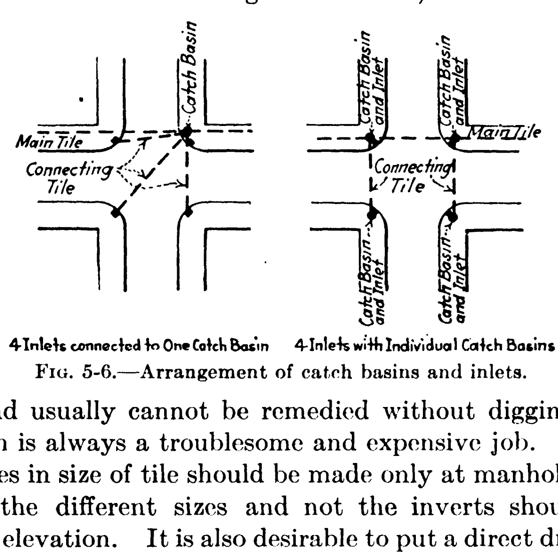


FIG. 5-6.—Arrangement of catch basins and inlets.

locate and usually cannot be remedied without digging up the tile which is always a troublesome and expensive job.

Changes in size of tile should be made only at manholes. The tops of the different sizes and not the inverts should be to the same elevation. It is also desirable to put a direct drop in the grade line of the tops of the tile at each manhole whether the size changes or not. This added fall through the manhole compensates to some extent for the interruption to smooth flow caused by the manhole and also gives an opportunity to adjust errors in leveling.

Details of manholes and catch basins are given in Chap. 12.

Tile.—Either vitrified clay or concrete tile may be used for storm sewers. Sewer pipe of the hub-and-spigot type are preferable to the plain-end tile as they can be laid true to line and grade and are not readily displaced. Vitrified clay tile are usually more economical in sizes under about 24 in. Above 24 in., concrete tile are ordinarily less expensive owing to the difference in cost of specials such as Y's and T's. Concrete tile

are generally more porous than vitrified clay pipe and in some instances have to be specially designed to resist abrasion due to silt in the water, which adds to their cost. For sewers larger than 60 in. some other type of construction than the monolithic tile is more economical. Segmental tile, brick arches, poured concrete arches and boxes, precast concrete units, etc., may be used. The type will be influenced by local conditions.

Tile carrying roof and basement water only may be as small as 6 in. but preferably not less than 8 in. Tile carrying street water should be not less than 10 in. to avoid clogging with floating debris. This size can be continued until its full capacity is reached.

Depth.—Sanitary sewers should be at such an elevation that the house connections can have adequate grades and enter the buildings well below the basement floor. This will require a minimum depth to the top of the sewer below the top of curb of 6 to 8 ft., depending on the ground slopes and the distance from the sewer to the buildings, in residence areas and probably more in business districts. Storm drains, however, need to be placed only deep enough to get sufficient cover or to receive proper connections from catch basins and inlets. This generally places the storm drain above the sanitary sewer and makes it easier to avoid conflicts in grade of the two conduits. Some cities place the storm drains low enough to accommodate basement and foundation drains. This is generally unnecessary since such connections can be made to the sanitary sewers and the added depth increases the cost. Combined sewers must be low enough to accommodate the basement drains, since they serve both the sanitary and storm flow needs.

House Connections.—When the storm drain is placed at the side of the pavement in the parkway T's or Y's should be inserted opposite each adjacent lot for making house connections. To accommodate the lots on the other side of the street *cross tile* should be provided, usually one to each two lots placed opposite the common lot line. These cross tile should be not less than 8 in. and should extend at right angles to the street and be connected to the main tile by T's. Their length should be such as to carry them at least 2 ft. out from under the pavement so that connections to them can be made without undermining the curb. A breeches or Y should be placed on the end so that the two house connections can be made independently.

If a drain or sewer is located under the pavement, *stubs* are provided for each side of the street, usually one for each two lots for storm drains and an independent one for each lot for sanitary sewers. These stubs should be constructed essentially the same as cross tile with their ends well out from under the pavement and with Y's or breeches on the ends if they are to serve two lots. Sanitary-sewer stubs are generally connected to the main tile

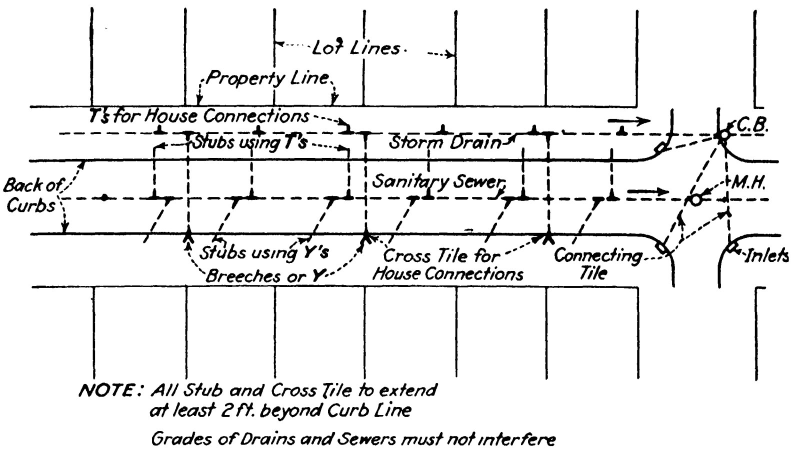


FIG. 5-7.—House connections for storm drains and sanitary sewers.

with Y's and run out diagonally, while storm-drain stubs are usually at right angles to the street and connected with T's.

These connections should be carefully located and exact records of their locations made so that they can be readily found when wanted. Incidentally, it is equally important that the records themselves be carefully preserved and kept where they can be readily found. It is good practice, too, to mark the location in the field in some reasonably permanent way. A cross or V chiseled into the pavement, curb, or sidewalk is often used.

Designing the System.—The layout, length, and grades of the proposed drains should be determined from an actual survey or a good topographic map. The points at which water will enter the system should next be definitely fixed. These should be the actual location of inlets as determined from street grades and not merely the low corners of blocks. The area contributing to each inlet should next be determined, together with its runoff factor.

Beginning with the highest area, the time of concentration t is estimated and the expected rainfall determined from Eq. 5-1.

The value of t should not be too short since this will result in too large a value of i. This in turn will make the tile sizes too large, especially lower down the system, since this initial value of t affects all the other values. For ordinary residential areas with street grades up to about 3 percent, values of t of 20 to 30 min. are suitable for an initial area of an ordinary block containing 2 to 3 acres. As the slopes increase, t should decrease to a lower limit of 10 to 15 min. In densely built-up areas with steep grades t may become as low as 5 min.

Since now the area, rainfall, and the runoff factor of the initial area are known, the expected discharge is computed from Eq. 5-2. The size of tile is now found from the diagram Fig. 5-1 or computed by Eqs. 5-4 and 5-10.

The time required for the water to flow through the tile to the next inlet can now be computed from the velocity and distance. This increment of time added to the previous value of t gives the time of concentration to be applied to the second area. The discharge from this second area is computed in the same manner as before and added to the discharge from the first area to give the amount of water to be handled by the second reach of tile. The size and velocity and value of t for the third area are determined as before. The process is continued until the outlet or end of the project is reached.

The preceding method is suitable for the smaller areas over which the storms may be expected to be fairly uniform in intensity. As the areas become large the storms become more variable, and a slightly different method may be more desirable. Each time a new value of t is determined, instead of it being applied only to the new area to get the increment of flow, it is applied to the entire preceding area—the sum of the separate areas—and the entire discharge at the new point determined at once. This involves determining an average value of r to be applied to the combined area. This value of r is the weighted mean of the values of r for the separate areas. This method will give values of Q slightly smaller than those of the first method.

Example.—Assume an initial area of 2.5 acres with $r = 0.3$, $t = 25$ min., and a storm frequency of 25 years located in a city in central Illinois. From Eq. 5-1a $i = \dfrac{181}{25 + 21} = 4.0$ in per hour. From Eq. 5-2

$$Q = 2.5 \times 4.0 \times 0.3 = 3.0 \text{ cu. ft. per second.}$$

With a grade of 0.3 percent the diagram shows the size of tile to be

15 in. and the velocity 2.5 ft. per second. Assume that there are 1,000 ft. of tile to the next inlet where a new area of 7.5 acres with $r = 0.4$ contributes water. The new value of t is $25 + \frac{1{,}000}{2.5 \times 60} = 32$ min. From Eq. 5-1a $i = \frac{181}{32 + 21} = 3.4$ in. per hour. From Eq. 5-2

$$Q = 7.5 \times 3.4 \times 0.4 = 10.2.$$

The amount of water to be carried by the second reach of tile is $3.0 + 10.2 = 13.2$ cu. ft. per second. With a grade of 0.4 percent the tile size is 24 in. and the velocity 4.0 ft. per second.

Following the second method of computation the tile size and velocity for the first area would be the same and t and i for the second area would be the same. This value of i, however, would be applied to the entire area of $2.5 + 7.5$ having an average value of r of 0.38; therefore,

$$Q = 10 \times 3.4 \times 0.38 = 12.9.$$

This is slightly smaller but would not change the size of tile chosen or materially affect the velocity.

When two drains unite, the tile below the junction must carry the combined flow from the two branches. If the two times of concentration are practically equal the expected flow in the main is the sum of the two maximum flows in the branches as computed above. If the two values of t are different the expected flow in the main is found in the following manner. First, the flow from branch 1 is computed by using the value of t for branch 2 and this result added to the maximum flow from branch 2. Next, the flow in branch 2 is computed with t from branch 1 and added to the maximum flow in branch 1. Whichever of these two values is the greater is taken as the value of Q for the main. Several branches uniting at a common junction can be treated in a similar manner.

BRIDGES

A *bridge* is a structure which carries a roadway over a stream, depression, or other obstruction. It consists of a *superstructure* supported at intervals on a *substructure* and is reached by *approaches.*

Substructure.—*Abutments* support the ends of the superstructure and act as retaining walls for the ends of the approach embankments. *Piers* support the superstructure at intermediate points between the abutments. Abutments and piers are now usually built of concrete, but masonry, steel, and wood are sometimes used. The substructure of a *trestle* bridge consists of *bents* of wood or reinforced-concrete *piles.*

Foundations.—The substructure must rest on an adequate foundation. Solid rock is best but is not always available. Shale, gravel, firm clay, etc., generally form acceptable foundations if the dimensions of the footings of the abutments and piers are proportioned to suit the different supporting powers of such soils (see Table 8-1).

Where only soft soils are encountered at reasonable depths, additional supporting power is developed by driving piles. Wooden piles for foundations may be of almost any available wood. They should be not less than about 7 in. in diameter at the point and 10 in. at the butt, and of sufficient length to develop the required support. They must be cut off below permanent water level to prevent decay. For trestle bents and other exposed purposes, only the best of woods should be used and even these should be creosoted or otherwise treated to resist decay. Such treatment is especially necessary in tidal waters where there is danger of attack by the teredo, limnoria, and other marine borers, or in dry work where termites and the like are found.

Reinforced-concrete piles are gaining favor despite their higher first cost. When properly designed and well made they are very durable and for trestle work more pleasing in appearance than wood piles.

Supporting Power of Piles.—Piles may be driven either with a pile driver or by water jetting. In either case the bearing power is due principally to the friction between the pile and the soil and not by direct support on the end.

Tests have shown that this friction varies from about 300 lb. per square foot of superficial area of the pile in soft mud to over 2,000 lb. in compact sand and gravel. A factor of safety of at least 2 should be used in ordinary soils and more than 2 in soft ground, since the latter may flow and permit gradual settlement.

The supporting power of driven piles in ordinary soil may be estimated from the *Engineering News Formulas* which are: For drop hammer,

$$P = \frac{2wh}{s + 1} \tag{5-11}$$

For steam hammer,

$$P = \frac{2wh}{s + 0.1} \tag{5-12}$$

in which P is the safe load in pounds, w is the weight of the hammer in pounds, h is the fall of the hammer in feet, and s is the final penetration of the pile in inches under a single blow. Judgment must be employed in interpreting the results from these formulas.

Superstructure.—The superstructure of a bridge consists of the *main members*, which carry the loads to the abutments or piers, and the *floor system*, which carries the traffic and transmits its weight to the main members.

The main members may be *beams* of wood, steel, or concrete; *slabs* of reinforced concrete; *girders* or *arches* of reinforced concrete or steel; or steel *trusses* or *cables*.

The framework of the floor system may be of wood, reinforced concrete, or steel. The floor itself may be of wood or any of the various types of road surfaces. All wood on permanent bridges should be creosoted.

Span.—A unit of the superstructure between adjacent supports is termed a *span*. The *length of span*, often expressed simply as *the span*, is the distance between adjacent supports. The *clear span* is the free distance between piers or abutments at the water level. The *actual span* is the distance center to center of supports. The *length* of a bridge is the total distance from abutment to abutment including all spans. The length of a bridge depends on the free opening required, the height of the roadway above the stream or other obstruction being crossed, and the relative cost of bridge work and earth embankment. The length of span is interrelated with the height of abutments and piers, the type of construction, and the needs of navigation.

Clearance.—The *clearance* is the distance from high water or other limiting object to the lowest point of the superstructure. The elevation of high water, the required clearance, and the distance from the clearance line to road surface fix the lowest permissible elevation of the grade line at a stream crossing. The clearance over railroad tracks is fixed by law in most states at about 22 ft. The minimum desirable clearance over a highway is about 14 ft.

The amount of clearance needed at stream crossings depends on the accuracy with which the elevation of high water is known, the character of the stream, and whether it carries ice or snags. There is a tendency to use too little clearance, since an increase in clearance means higher abutments, piers, and approaches, and

hence increased cost. A minimum of 2 to 3 ft. has been used, but a minimum of at least 5 ft. would be better. With much ice or large snags at high-water time more clearance is needed. Over navigable waters the requirements of navigation may control the clearance and in this country the limits of clearance and span length are regulated by the War Department.

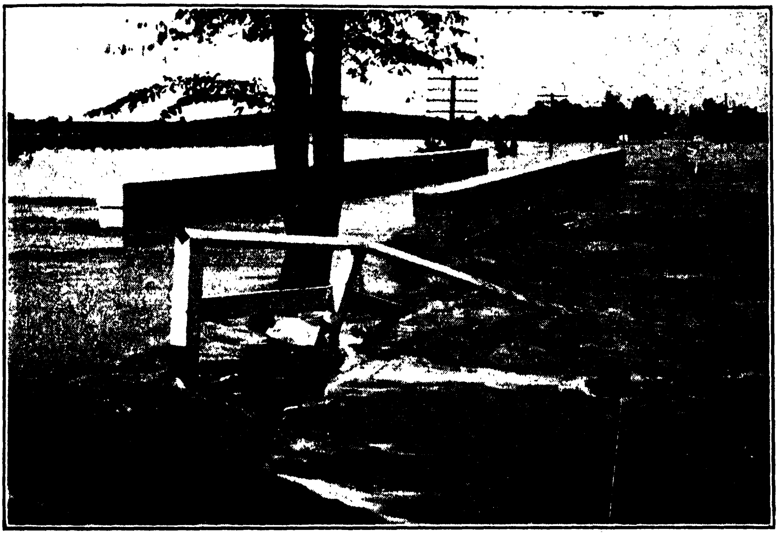


FIG. 5-8.—A concrete-girder bridge during an unusual flood.

Area of Waterway.—The area of waterway required at a bridge or culvert is governed by the amount of water and its rate of flow. These factors are in turn controlled by the area and shape of the watershed, the amount of rainfall, the runoff factor, and the slopes of the ground. Frequently sufficient information to fix the size of opening can be obtained from other structures in the vicinity. On the other hand, it may be necessary to estimate the size of opening from very meager data. Where the necessary factors can be determined, the required opening can be computed in the same manner as previously outlined for open ditches.

Various empirical formulas have been suggested as aids. One of the most widely used, on account of its simplicity and reasonable reliability, is *Talbot's:*

$$a = CA^{3/4} \tag{5-13}$$

in which a is the required area of waterway in square feet, A is the drainage area in acres, and C is a variable coefficient depending on the size, shape, character, and slopes of the watershed. For steep, rocky ground, C varies from 0.7 to 1.0. For agricultural country subject to spring floods and with the length of valley three or four times its width, C may be 0.3 to 0.5. With longer and narrower valleys, flatter slopes, and freedom from melting snow, C may be reduced to 0.1 to 0.2. C should be increased for steep side slopes, steep slopes in the upper part of

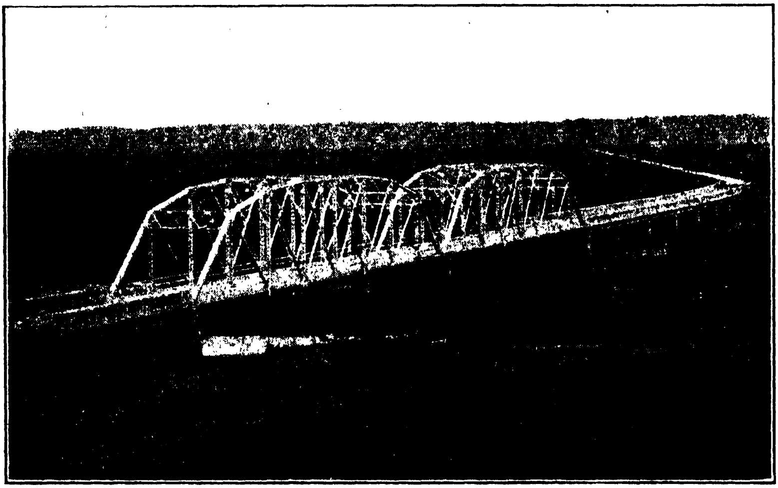


FIG. 5-9.—A pleasing structure. Through steel trusses with concrete deck-girder approach. Note area of waterway for an apparently small stream.

the valley, and when the valley is short compared with its width.

This formula is simply a guide to the judgment. It was derived for conditions in the Mississippi Valley where stream velocities are generally under 10 ft. per second and maximum rainfall about 4 in. per hour. It can, however, be adapted to other conditions by a proper choice of C. Its results should be checked with the best evidence at the bridge site. It should be remembered, however, that high-water elevation and width of valley do not necessarily fix the required opening. The conditions in the stream may be such that there is a wide width of slack water and only a comparatively small waterway is needed (see Fig. 5-9).

Location.—The location of a bridge is governed by the alinement of the road and the availability of a suitable bridge site.

A crossing at right angles to the stream is desirable from the standpoint of the structure but in no case must this be obtained at the sacrifice of safety and the convenience of the roadway. It must be remembered that a bridge, no matter what its magnitude, is not an end in itself but only a means to an end. Therefore, the roadway and later the traffic should not be adjusted to

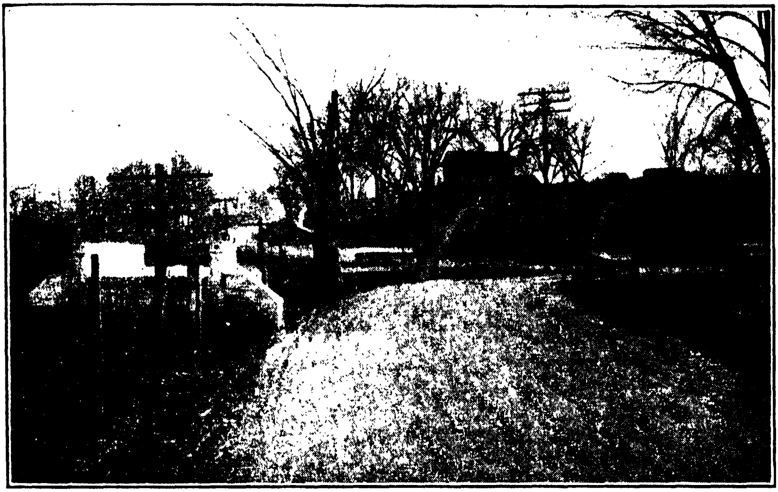


FIG. 5-10.—New concrete girder replacing old steel pony truss. Note the relocation to improve the alinement of the road. The old road accommodated itself to the bridge. The new bridge accommodates itself to the road.

the bridge but the bridge and approaches should be designed to fit the traffic requirements. There is always a certain amount of "give and take" but in general the bridge should do the giving and the road the taking. The magnitude of a structure should never be permitted to overshadow its purpose.

CULVERTS

A *culvert* is a transverse drain or passageway under a roadway. In a sense it is a small bridge but differs from a bridge in that the substructure and superstructure are united into a single unit, usually with a complete periphery. In general, culverts are of small span. Some authorities designate a culvert as having a span under 10 ft. but there are many structures of much greater span that are true culverts.[1]

[1] The P. & E. Ry. crosses the North Fork of the Vermillion River at Danville, Ill., on a "double-fifty" culvert consisting of twin tubes each of 50-ft. span.

A culvert consists of two parts, the *barrel* and the *head walls.* The barrel forms the channel of the culvert and is an essential part of the structure. The head walls serve to cut off erosion around the barrel, guide the flow, and hold back the earth from the channel. The head wall, however, may be omitted by lengthening the barrel. Culverts are known as *pipe culverts, box culverts,* and *arch culverts,* depending on the shape of the barrel and may be further classified by the material from which they are made.

Pipe Culverts.—Pipe culverts have the barrel made of some form of pipe. They are suitable for the smaller sizes but may be used up to the maximum available size of the pipe. Pipe culvert should never be smaller than 12 in. to avoid clogging. Head walls may be of timber, loose rubble, masonry, or concrete. The two latter are the best and should be used in high-grade construction. Head walls are often omitted with smaller sizes. This is usually objectionable for regular road culverts but may be permitted at farm entrances by lengthening the pipe to accommodate the earth slopes.

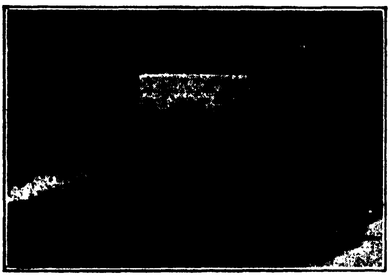


FIG. 5-11.—A tile culvert at a farm entrance.

Tile culverts are made of common farm tile, vitrified tile, either plain or sewer pipe, and concrete tile, either plain or interlocking. Sewer pipe or interlocking tile are preferable to plain tile because they retain line and grade better but they are somewhat more expensive. Sometimes the tile are encased in concrete. In this case the tile serve primarily as forms for the concrete and common farm tile may be used to advantage.

Corrugated pipe of steel or ingot iron is often used. The ingot iron is much more durable and all should be well galvanized after forming. Corrugated metal pipe may be used to advantage for temporary or semipermanent construction and especially where the cost of transportation is high. In general, the price of corrugated-pipe culverts is not sufficiently low to justify its use in permanent work of high class. On the other hand, ease of installation, immediate use, and similar factors may make their use both logical and economical in certain locations. Corrugated

pipe is sometimes derisively called "wrinkled tin" or "tin whistles." This is due largely to ill-advised or, more frequently, improper installation or sometimes to poor material.

Cast-iron pipe is expensive but is suitable where heavy loads are to be carried. It was formerly much used by railroads for all small culverts and is now often employed in carrying sewers under railroad tracks, especially where the sewer is shallow.

Masonry pipe of brick, stone, or concrete block are sometimes used.

Box Culverts.—A box culvert is made in the form of a box with top, sides, and bottom but with open ends. Sometimes the bottom is omitted and the sides supported on footings.

Wood box culverts were formerly much used. They are short-lived and relatively expensive but may be justifiable on temporary work or where lumber is cheap.

Concrete box culverts constitute one of the most popular types at the present time on account of their reasonable cost, long life, and great adaptability. They may be made with plain concrete

TABLE 5-4.—CONCRETE BOX CULVERT DIMENSIONS

Span, feet	Maximum height inside box, feet	Maximum fill on box, feet	Thickness, inches		Main steel in top and bottom of box	
			Box	Head wall	Size of square bars, inches	Spacing, inches
2	4	4	6	8	3/8	8
3	4	4	6	8	3/8	6
4	4	4	6	8	1/2	6
5	7.5	1	7	8	1/2	7
6	7.5	1	7	8	1/2	5
7	7.5	1	7	8	5/8	6
8	7.5	1	7	8	5/8	4¾
9	9	1	9	12	5/8	5½
10	9	1	9	12	3/4	6½
11	9	1	9	12	3/4	5½
12	9	1	9	12	3/4	5

sides and reinforced tops and bottoms or be fully reinforced in tops, bottoms, and sides. The latter is the most common. Table 5-4 gives the essential dimensions of some concrete box culverts actually used. These culverts are conservatively

designed and may be safely used, within the limits of dimensions given and for the maximum present highway loads.

Sectional precast concrete culverts are on the market and some are of merit. On high-class roads where the work is well designed and inspected they have little in their favor. On outlying roads where supervision is meager they are often advisable and economical.

Arch Culverts.—Arch culverts are similar to box culverts except that the tops are arched. Reinforced concrete, plain concrete, or masonry is used. The arch culvert is less used

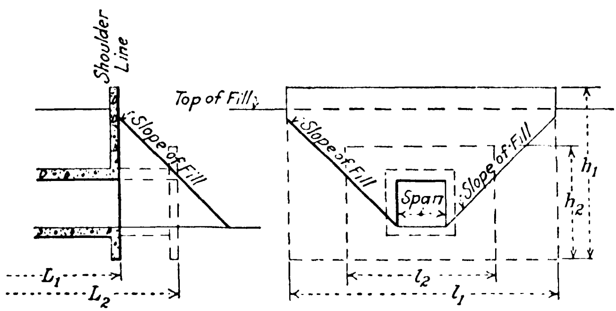


FIG. 5-12.—Relation of length of barrel to height and length of head wall.

than formerly except where conditions of appearance make it desirable or available materials make it economical.

Length of Barrel.—The minimum length of barrel should invariably be such that the head walls will come at or outside the shoulder lines. The roadway should never be narrowed at a culvert on account of safety for traffic.

If considerable fill is required, economy may result by increasing the length of barrel which will result in decreasing the height and length of head walls as shown in Fig. 5-12. The economical length of barrel relative to height and length of head wall can be determined for any given location by computing the respective amounts of materials.

Head Wall.—The *height of head wall* should be such as to extend well above the earth where it intersects the slope. A minimum of 1½ to 2 ft. should be used. The head wall should also extend below the barrel at least 2 ft. At the upstream end this acts as a cutoff wall to prevent seepage along the barrel which might develop into a washout. At the downstream end it prevents eddies from eroding the soil from under the end of the

culvert. In some cases the bottom of the culvert may be extended as an apron to prevent such erosion. In this case a cutoff wall extending at least 2 ft. below the stream bed should be placed at the lower end of the apron.

The *length of head wall* depends on the span, the clearance, the depth of fill at the headwall, and the natural slope of the fill. The length must be such that the toe of the fill which extends around the end of the head wall will not encroach on the stream channel.

If the head walls are not parallel to the roadway, the method of determining the length is the same as for the straight head wall except for taking into consideration the angle of flare. The height of the flared wing wall decreases towards the end. The amount of this decrease depends on the angle of flare and the side slopes.

Appearance.—Culverts are usually placed where they are comparatively inconspicuous. This should not be an excuse for utter disregard for appearance but does permit a minimum amount of ornamentation. A very long, high head wall should be relieved from bareness at least by simple paneling. If it is exposed to general view as in a park, considerable attention should be given to the appearance.

Problems

5-1. An area 660 by 660 ft. in a city in northeast Texas has an estimated time of concentration of 25 min. What intensities of rainfall can be expected for storm frequencies of 10, 25, and 50 years?

5-2. If the runoff factor for the area in Prob. 5-1 is 0.3, what would be the discharge in cubic feet per second for the 25-year storm?

5-3. What size of tile would be required on a grade of 0.4 percent and what would be the velocity of flow for the runoff in Prob. 5-2? Compute by the equations and check by the diagram.

5-4. After a distance of 1,200 ft. the tile in Prob. 5-3 is joined by two others from similar areas. What are the new time of concentration, rate of rainfall, discharge, and size of outlet tile on a 0.3 percent grade for the same 25-year storm?

5-5. A section of road $\frac{3}{4}$ mile long in central Ohio has an area averaging $\frac{1}{4}$ mile wide on each side of it contributing water to its ditches. The outlet must be an open ditch on a 0.1 percent grade in which the water cannot be more than 4.0 ft. deep. The estimated time of concentration is 40 min., the runoff factor 0.25, and the storm frequency 10. Determine satisfactory dimensions for the ditch using 1:1 side slopes.

5-6. The outlet tile of an underdrainage system is on a 0.36 percent grade. What size is required if the area is 160 acres and the drainage modulus 0.4?

5-7. What should be the total crown of an earth road 30 ft. wide, a gravel road 24 ft. wide, a concrete pavement 40 ft. wide, and an asphalt pavement 56 ft. wide?

5-8. Compute the area of waterway for a culvert taking the flow from 1,800 acres of ordinary farm land on moderate to flat slopes.

5-9. What is the bearing power of a steam-driven pile which penetrated 1.5 in. under the last blow of a 4,000-lb. hammer having a stroke of 24 in.?

5-10. What is the bearing power of a jetted pile 10 in. in diameter extending 15 ft. into clay?

5-11. Determine the length of head wall 12 in. thick for a box culvert whose span is 10.0 ft. and the height from bed of stream to edge of roadway is 12.0 ft. if the fill slopes are $1\frac{1}{2}:1$.

CHAPTER 6

EARTHWORK

GENERAL

The process of road building always involves the movement of more or less earth. If the longitudinal slopes are satisfactory, only a certain amount of lateral earth movement is necessary to give the road the desired cross-section. The amount of earth so moved is not large but considerable refinement in its excavation and distribution may be necessary. If the slopes must be changed to give a desired grade line, earth must be moved longitudinally as well as laterally. The amount of earthwork in this case may vary from only small quantities necessary to eliminate minor undulations of the ground to almost any quantity where heavy cuts and high embankments are required.

Cut and Fill.—Where the ground must be lowered to the desired grade, *cut* is necessary. The material is excavated, moved some distance, and deposited, usually in an adjacent embankment. If the amount is greater than the fill requires, the excess becomes *waste* and is deposited in a spoil bank. Where the ground must be raised to the desired grade, *fill* is required. Wherever possible, the fill is made of the material from adjacent cuts. If the cuts do not supply sufficient material, *borrow* is necessary.

All cut, including waste and borrow, is paid for at the price of *excavation*. Fill is not paid for since it is made either from cut material which must be placed somewhere or from borrow. Excavation is measured in the cut or borrow pit. The unit is the cubic yard.

Haul.—Haul is the work done in moving earth from the point of excavation to the place of deposit. The unit is the *yard-station* which represents the work done in transporting 1 cu. yd. a distance of 100 ft. *Free haul* is the haul included in the price of excavation. The *free-haul distance* is the distance every cubic yard is entitled to be moved without an additional charge for

haul. *Free-haul yardage* is the number of cubic yards moved at the price of excavation, *i.e.*, without any overhaul charge.

Overhaul is haul in excess of that included in the price of excavation. The *overhaul distance* is the average distance a given *overhaul yardage* is moved, less the free-haul distance. The product of the overhaul yardage and overhaul distance gives the overhaul. Overhaul originated and is still used on railroad work. On highway work, and especially city street work, overhaul is less used. It is becoming customary for the earthwork distri-

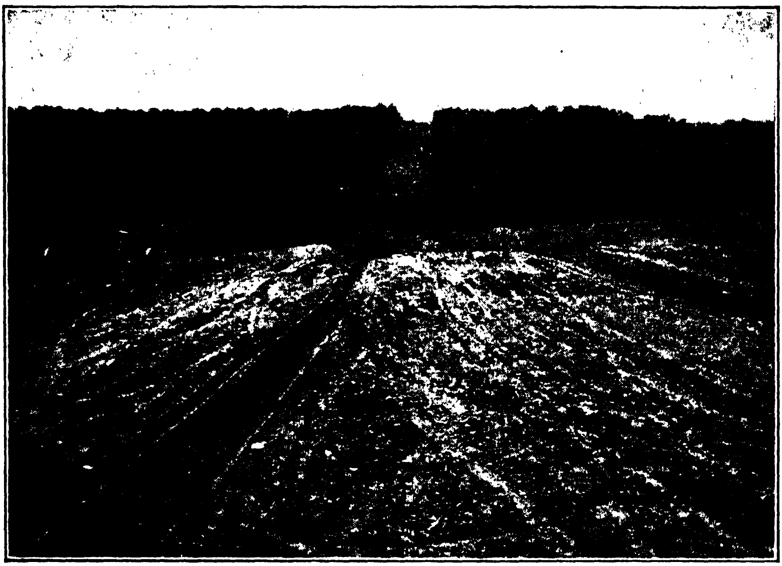


FIG. 6-1.—Starting the earthwork for a trunk road. Note the furrow cut by the elevating grader.

bution to be worked out with considerable exactness and for the contractor to bid on the job completed according to the plans. This, however, does not cover the contingency of a change in plans during construction. In city work, overhaul is often eliminated by increasing the freehaul distance.

The *limit of profitable haul* is the distance at which the cost of overhaul equals the cost of excavation, and consequently it is the distance beyond which it is cheaper to waste the cut and borrow the fill. Obviously the limit of profitable haul is equal to the price of excavation divided by the price of overhaul plus the free-haul distance. If additional right-of-way must be

purchased to accommodate either the spoil bank or the borrow pit, the net cost of this land divided by the number of cubic yards accommodated should be added to the unit price of excavation and a new limit of profitable haul computed. If this new limit eliminates the necessity of borrow or waste, it is preferable to do the work in this way. Sometimes it is necessary to pay overhaul on borrow and waste.

Earthwork Classification.—Since different materials vary in their ease of excavation or handling, and consequently in the cost

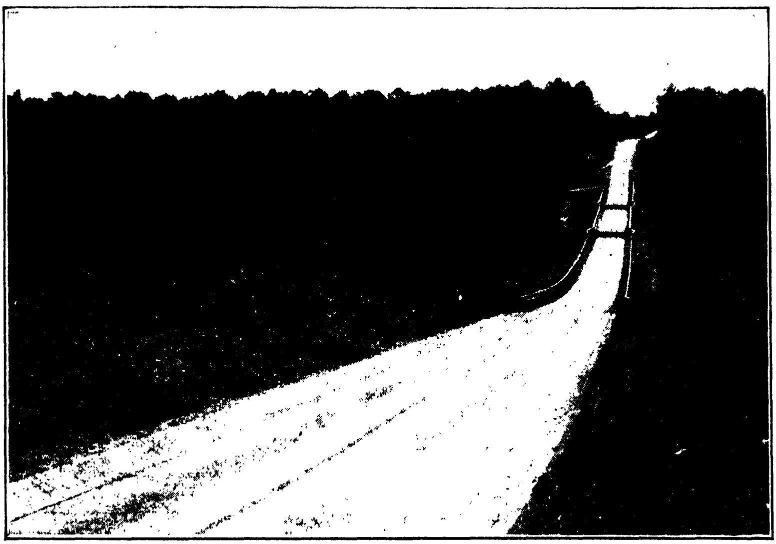


Fig. 6-2.—The completed work. Note the cut and fill, also the berm back of the gutters.

of doing the work, it is usual to make several classifications of the material and call for bids on each.

Generally, three or four classes are made about as follows:

Earth excavation includes those materials which may be excavated with ordinary equipment including plows, scrapers, steam shovels, etc., but which does not require, or which is not aided by, blasting.

Soft-rock excavation includes shales, cemented gravels, shelly rock, etc., which may be excavated with heavy equipment but in which the work may be facilitated by light blasting.

Loose-rock excavation includes mixtures where part can be excavated without blasting while part requires blasting. Usu-

ally a limit is placed on the size of mass which separates loose rock from solid rock.

Solid-rock excavation includes those rocks which can be removed only by blasting.

To the foregoing is often added a factor of *wet excavation* when the work must be done totally or partially submerged. Often only earth and solid-rock classifications are made but, if there is likely to be any considerable amount of other classes, provision should be made for them in the earthwork specifications.

COMPUTATIONS

The mathematics of earthwork involves the determination of the number of cubic yards of cut, fill, waste, and borrow for each class of excavation, and the determination of overhaul.

All volume calculations are based on the *end-area* method. In this method the area of the earthwork cross-section is determined at suitable intervals. The average of each pair of end areas is then multiplied by the distance between them to determine the volume. The usual interval between cross-sections is one station, *i.e.*, 100 ft., although sometimes 50-ft. intervals are used. Under some conditions the *prismoidal method* is employed, usually in the form of the *prismoidal correction*. This is justifiable only in high-priced excavation and where the quantities are large.

All earthwork computations are dependent on a certain amount of field data. The more precise the earthwork is to be figured, the greater the amount of data required. For preliminary studies only a profile and tentative grade line are necessary and the volumes are taken from previously computed tables based on level sections. For estimates on which to receive bids, cross-sections are taken in the field from which the volumes are determined. During construction still further field data may be obtained and the final volumes computed.

Areas of Sections.—When slope stakes have been set and cross-sections so taken, the end areas may be computed by the methods given in the standard books on railroad earthwork. Correction must then be made for the side ditches and the trench for the pavement slab.

If the areas are determined from cross-sections taken previously to the field location, the graphical method is almost universally used. The cross-section from the field notes is platted to a suitable scale on ruled cross-section paper. The new cross-section

is also platted and the area between the two determined by counting the ruled squares or preferably by means of a planimeter. The planimeter should be carefully checked to the scale of the paper and each area should be planimetered at least twice. This method gives very reliable results when carefully done and with an accuracy quite in accord with the field data. Cut areas and fill areas are taken separately. In platting the new cross-sections the side ditches and slab trench, if any, are included. A standard cross-section template cut from transparent celluloid greatly facilitates the work.

Swell and Shrinkage.—Practically all materials increase in volume when first excavated. When placed in the embankment they decrease again in volume. If the final volume of the fill is less than the volume of the cut from which it is made, the decrease is termed *shrinkage*, if greater the increase is *swell*. Swell may be considered as negative shrinkage.

Few soils actually shrink, *i.e.*, actually decrease in volume and none shrink a large amount, but, owing to inaccuracies in measurement, imperfections in the computation methods, and especially to loss of materials during haulage and compacting, the decrease in volume or apparent shrinkage is often considerable between cut and fill. A few soils swell somewhat, while solid rock swells considerably, often as much as 100 percent, owing to the breaking of the stone into irregular pieces which do not fit together and thus introduce voids.

Shrinkage Factor.—The *shrinkage factor* is the coefficient by which the fill volumes are multiplied to determine the volume of cut required to make the fills. If this factor is less than unity, there is swell; if greater than unity, there is shrinkage. For solid rock the shrinkage factor is 0.5 to 0.8, for loose and soft rock 0.7 to 1.0, for ordinary soils 1.0 to 1.3.

When cuts and fills are shallow, the loss of earth during construction is relatively high, as are also the errors in field work and computations. The result is that the shrinkage factor must be larger for shallow cuts and fills than for deeper ones. In ordinary soils the factors should be about 1.3 for depths less than 2 ft., decreasing proportionately to about 1.1 for depths over 5 to 8 ft.

Settlement.—Settlement is the decrease in height of embankment when finally stable from what it was when first constructed. The amount of settlement varies with the soil and the method of compacting. Rock, gravel, and sand fills settle but little. Earth

fills may settle 20 percent if loosely constructed. When made with wheel or slip scrapers, etc., the settlement is ordinarily 8 to 10 percent. If well made in thin layers and well rolled, the settlement may be reduced to 2 to 4 percent. It is practically impossible to construct an earth fill by ordinary methods that will not settle somewhat.

Beginning about 1925 the Illinois Division of Highways developed a process of *water soaking* or *puddling* the fills so as to secure immediate compaction and thus eliminate future settlement. While puddling may be accomplished by thoroughly wetting each layer of soil while the fill is under construction, the more economical method is to saturate the entire embankment after it has been built in the usual way. To accomplish this, holes are jetted into the embankment at intervals of 6 to 10 ft. each way and extending to within 1 or 2 ft. of the natural ground surface. Water is then pumped into the holes until the entire fill is saturated, care being taken that the water does not break out through cracks or fissures and cause erosion. Settlement of the embankment always occurs during and immediately following the jetting but practically none takes place after the soil is dried out to normal moisture content. At least 2 weeks are allowed for the fill to dry out.

Bridge approaches are especially troublesome. It is almost impossible to compact the soil close up to the abutments, with the result that settlement is considerable and continues for a long time, making it difficult to maintain the road surface to grade. Puddling can be made to solve the problem if care is taken to prevent excessive pressures against the abutments by the saturated soil during the puddling process.

Balancing Cut and Fill.—Within the limits of profitable haul it is cheaper to make the fills from the adjacent cuts instead of from borrow. Therefore, it is always desirable to balance cut and fill as nearly as possible. In laying a grade line the attempt is made to so place it as to make the earthwork balance. In so doing, however, care must be taken not to insert objectionable features into the grade line merely to save earthwork. The importance of balancing earthwork has often been overemphasized and many a grade line has been spoiled in order to save a few yards of excavation or a few cents in overhaul costs.

In shallow grading and on side-hill work, both cut and fill frequently occur at each cross-section. The first step is to

balance the earthwork laterally. Each fill volume is multiplied by the chosen shrinkage factor and subtracted from the cut at the same station. If the result is positive, an excess of cut exists and earth must be moved away from that section. If the result is negative, fill is in excess and earth must be moved in to complete the embankment. Thus the net amount of earth to be moved longitudinally is the difference between the cut and fill at

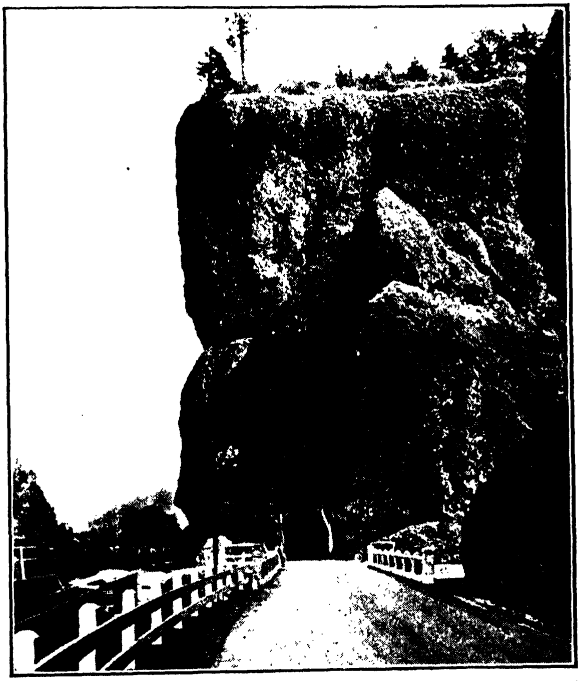


FIG. 6-3.—Saving excavation and preserving natural beauty by tunneling. The tunnel at Oneonta on the Columbia Highway in Oregon.

each station. In heavy grading, except on side hills, cut or fill only normally exists at each station; hence this lateral balancing is absent.

In side-hill work, both cut and fill normally exist at each station. The relative amounts of the two can be changed either by a change in the grade line or a change in the horizontal alinement. The problem is therefore to find a combination of grade line and center line which will give the least excavation and the best balanced earthwork. A tentative grade line and alinement are chosen, the cut and fill determined, and the earthwork

balanced laterally. If a large excess of either cut or fill remains and it cannot be satisfactorily reduced by a change in the grade line, a new alinement should be taken and the process repeated. Such changes in alinement should be carefully considered with respect to curvature, safety, and convenience. After an alinement and grade are found which give a minimum of residual earthwork after the lateral balancing, the remainder is distributed longitudinally in the usual way.

By inspection, trial summations, and approximations it is possible to determine points between which cut and fill will balance longitudinally, and to compute the amount of haul required. This method is slow and inconvenient and does not permit of ready comparison with alternative schemes of earth distribution. It is therefore more common, and also better, to use the mass diagram.

Mass Diagram.—The mass diagram is a graphical method of securing an economical distribution of the earthwork, locating balance points, and of determining the amount of haul. The first step is to construct the *mass curve*. This is done by platting to suitable scales the summation of the total net earthwork between some point taken as the origin and any other point. The origin is generally taken at some point past which earth cannot move, as, for example, the beginning of the work, or a stream crossing. Cuts are considered positive and fills negative, and the summation is algebraic. Fill volumes are multiplied by the shrinkage factor, and if cut and fill exist at the same station only the net remainder after lateral balancing is used in computing the mass-curve ordinates.

From the method of constructing the mass curve it is evident that:

1. It ascends for cuts and descends for fills.
2. It is a maximum at a change from cut to fill and a minimum at a change from fill to cut.
3. Cut and fill balance between the two points where any horizontal line cuts the curve.
4. The vertical distance between any two points on the curve represents the total volume of earthwork in the horizontal distance between the same points.
5. The area between the curve and a horizontal line fixing balance points represents the total haul between the balance points.

By making use of these five principles, balance points, the economic distribution of the earth, and the amount of overhaul can be readily found. One method of doing this is indicated in Fig. 6-4. Another method is to use a planimeter to determine the areas representing the haul in accordance with the fifth principle given above.

In using the mass diagram, it should be remembered that there are several possible schemes of distribution but each of these can be spotted on the diagram and compared. The use of the diagram, therefore, requires some judgment and experience for good results. Referring to the second principle stated above

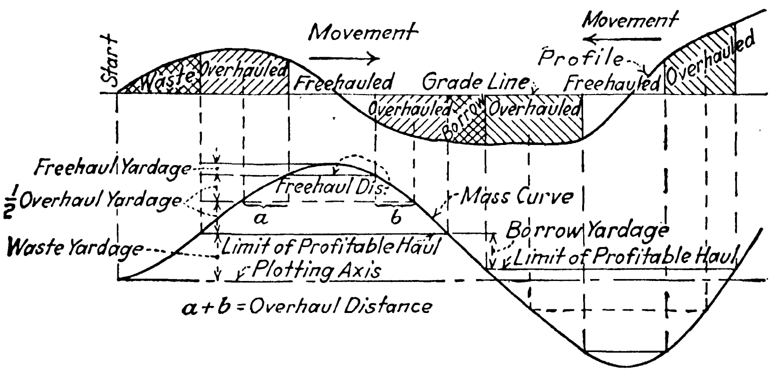


FIG. 6-4.—Mass diagram.

it often happens, when cut and fill both exist at the same station, that the crests or sags of the mass curve do not appear opposite the grade points as shown by the intersection of the grade line and the center-line profile and also that the distribution does not agree with the apparent size of cut and fill as shown by the profile. This is to be expected under these conditions but it has sometimes been misleading to the inexperienced.

Street Excavation.—City pavements are normally in cut, except on filled-in ground, and usually follow the ground surface rather closely. Balancing of cut and fill is therefore of rare occurrence or necessity.

It is customary to pay for the excavation of a trench just wide and deep enough to receive the pavement except when the cut to top of curb is more than 3 or 4 ft., when side slopes may be included. The cross-section of street excavation is, therefore, simpler than that of a rural road but the plan is more complicated

on account of street and alley turnouts and curb radii. The following method of computing earthwork will be found convenient, rapid, and sufficiently accurate, except in unusual cases when recourse must be had to the longer methods.

In Fig. 6-5 the area of the section is the sum of the two trapezoids $ADEB$ and $BEFC$ and their area is equal to $\dfrac{w(a + 2b + c)}{4}$. The quantity $\dfrac{a + 2b + c}{4}$ may be termed the *average ordinate o* of the section.

Obviously the ordinates a, b, c should go to the top of the subgrade. It is somewhat inconvenient to compute them in

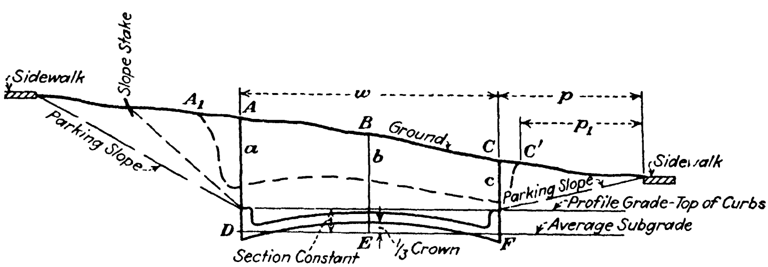


FIG. 6-5.—Cross-section for street excavation.

this way since there is a different grade elevation at each ordinate. It is simpler to compute the ordinates to the top of curb or to the crown of pavement as given by the profile grade, average them, and then correct the average ordinate by the section constant. The *section constant* is the distance from the *average subgrade line* to the crown of pavement or to the top of the curb, whichever is represented by the profile grade. The average subgrade line for circular or parabolic cross-section lies one-third the subgrade crown below the crest of the subgrade.

The ordinates may be computed directly from the grade-rod and ground-rod readings without reducing them to elevations.[1] If an occasional value of a, b, or c is negative, indicating fill, it is included with its negative sign since averaging it in approximates locating a grade point. If an entire section becomes fill, the grade points should be determined and the cuts and fills on each side of it computed separately. The fills can also be computed by means of an average ordinate.

[1] A calculating machine of the Monroe type greatly facilitates the work.

The volume between any two cross-sections by the end-area method is

$$v_1 = \left(\frac{o_1 + o_2}{2} + k\right)wl \tag{6-1}$$

but wl is the area of the pavement and $\frac{o_1 + o_2}{2}$ is the average of the two average ordinates and may be termed the average ordinate for the volume, and k is the section constant.

Summing up the volumes between successive sections for the length of the pavement and reducing,

$$V = AO \tag{6-2}$$

where V is the total volume, A is the total *surface area* of the excavation, and O is the *grand average ordinate,* given by the equation

$$O = \frac{o_1 + 2o_2 + 2o_3 \cdot \cdot \cdot 2o_{n-1} + o_n}{2(n-1)} + k \tag{6-3}$$

Theoretically, the preceding equations apply only to a volume of constant width with cross-sections uniformly spaced. Practically, however, it can be used with a variable width and made to include street and alley turnouts, curb radii, etc., by assuming that the average ordinate of the straightaway applies with sufficient accuracy to the entire area, which is generally the case. It is, therefore, not necessary to compute the turnout volumes separately.

The steps in the computation of the volume are as follows:

1. Compute o_1, o_2, o_3, etc., the average ordinate at each section.
2. Determine the section constant k.
3. From these values compute the grand ordinate O.
4. Compute the superficial area of the excavation A. If curb excavation is included with the curb and not with the pavement, A is the area of the pavement. If curb excavation is included with the pavement, A is the combined area under pavement and curb.
5. Compute V, remembering to take into account the various units involved.

Grading Parkings.—With reference again to Fig. 6-5 it is evident that the end area of the parking cut to the right is equal to the triangle whose altitude is p and whose base is the ordinate c

taken to top of curb. If the parking is to be graded back to the sidewalk line, p is constant; hence the volume for one side of the street is

$$V_1 = \tfrac{1}{2}pLC \tag{6-4}$$

where C is the average of all the ordinates c and L is the length of the parking. It is sufficiently accurate to make L equal the length of the street less the sum of the widths of street and alley turnouts.

If the width p is the same for both sides, the total volume is

$$V = pLx \tag{6-5}$$

where x is the grand average of a and c.

Frequently, a pavement is laid on a street already partially graded as shown by the dotted line in Fig. 6-5. In this case, an extra set of readings should be taken at C_1, and A_1 and p_1 determined.

If the parking is only to be semifinished, the earthwork may be included with the pavement excavation at the same price. If it is to be finished ready for seeding, the finishing work is high compared with the volume of excavation and allowance should be made in the yardage, in the price per cubic yard, or by including an item of finishing. This will cost from 3 to 8 cts. per square yard.

If the cuts are deep, and normal side slopes are to be used, the position of the slope stake should be determined, either in the field or on a platted cross-section, and the volumes computed from the triangular end areas.

Approaches.—At the ends of turnouts onto unpaved streets, grading must be done to accommodate the cross streets to the new level. Likewise, on rural highways, intersecting or connecting roads must be brought to the new grade. The length of these approaches must be enough to give an easy approach which for safety should not be more than 5 to 7 percent. The earthwork should be estimated and included in the total.

EQUIPMENT

A great variety of equipment is used in earthwork operations. It is not possible to give here a detailed discussion of all machinery. The following brief outlines, however, will indicate the general characteristics of the principal tools.

Hand Tools.—Spades, shovels, picks, mattocks, tampers, etc., must be included in the equipment of every grading crew. Their use is auxiliary to all other equipment.

Plows.—Plows of different types are often used in grading work. The *rooter* is a heavy implement with a single-pointed bottom without mold board. It might well be called a single-pointed scarifier. It is used to break unusually hard soil of all types. It is usually pulled by from two or four horses or a

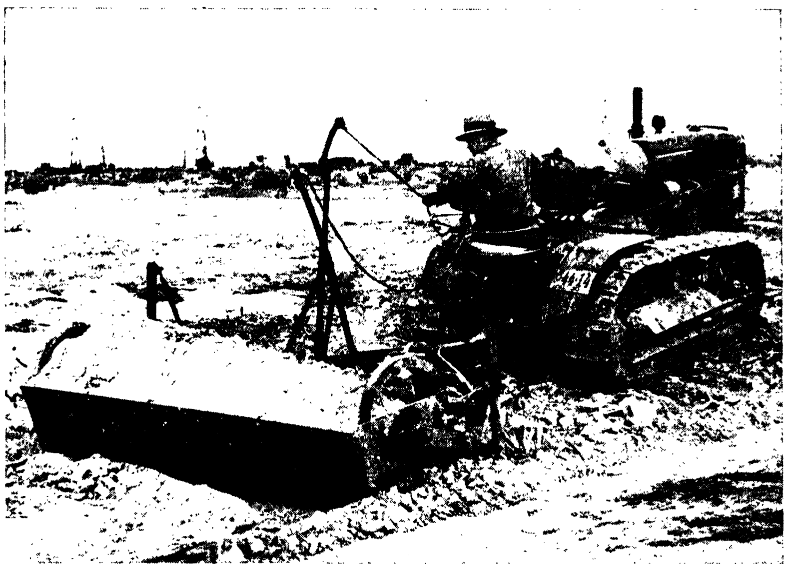


FIG. 6-6.—A rotary fresno often called a *tumble-bug*.

tractor. The *breaker* is a heavy plow of narrow width but with a mold board. It is used in heavy or virgin soils. *Ordinary plows* are used wherever adaptable, since they will loosen more soil with a given number of rounds than the preceding types.

Slip Scraper.—The slip scraper is shaped like a scoop shovel. It has a bail at the front to which the team is hitched and a pair of handles at the rear for loading and dumping. Its capacity is $\frac{1}{4}$ to $\frac{1}{3}$ cu. yd. and its economic hauling distance about 200 ft. It is not a digging tool; hence the soil must be plowed or otherwise loosened.

The slip is the simplest power tool and is very versatile in its adaptation to different kinds of work. A few slips should form

a part of every grading outfit since they can be used in locations which cannot be reached by larger tools.

Fresno.—The fresno is somewhat similar to the slip but is wider and shorter and has larger capacity. It is efficient only

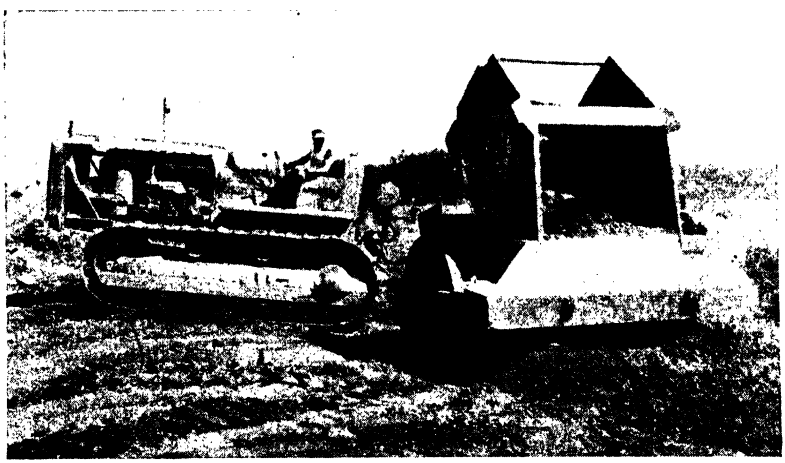


FIG. 6-7.—A 7-yard rear-dumping scraper pulled by a large caterpillar tractor.

FIG. 6-8.—An elevating grader. It is equipped with a gasoline engine to drive the elevators but is pulled by a tractor.

in loose soils but has an economic working range of about 400 ft. The *rotary fresno* (Fig. 6-6) is similar in shape but of larger size. It is made so that it rolls completely over in loading and dumping. It is pulled by a tractor and has its controls so

arranged that the tractor operator also operates the fresno, thus making a one-man outfit.

Wheeled Scrapers.—The *wheeler* has a two-wheeled axle from which is suspended a scoop similar to the slip, which can be raised and lowered by means of a lever. Its capacity is larger than that of the slip and its economic range 400 to 500 ft. The *maney* has four wheels and the scoop is raised from the loading position by a chain drive from the wheels. Its capacity is 1 to 2 cu. yd. Two or more maneys may be coupled in the form of a train and pulled by a tractor.

Scrapers having capacities of 5 to 7 cu. yd. are built in various styles. They are always pulled by large tractors and in some kinds of work have been very efficient (see Fig. 6-7).

Elevating Grader.—This machine (Fig. 6-8) consists of a heavy frame mounted on four wheels carrying a heavy braking plow, usually of the disc or colter type. This plow turns the soil on to an endless belt conveyor which carries it up and to the side so that it can be discharged into wagons or trucks or into a ridge beside the machine. In the smaller machines the elevator belts are driven from the wheels. The larger sizes have an independent gasoline engine to drive the belts. The elevating grader is best adapted to cuts of considerable length and fairly uniform depth in ordinary soils. To be efficient it must have an adequate battery of hauling equipment so that it can be kept moving continuously. A caterpillar tractor is the best motive power.

Power Shovel.—The power shovel (Fig. 6-9) is especially adapted to heavy excavation. Usually a *traction* shovel with caterpillar treads is used on road work. On railroads and on very heavy work a *railroad shovel* running on a track is frequently preferred. A light shovel arranged to cut parallel with its treads is often used on city pavement work. A gasoline or diesel engine is the usual source of power for modern road shovels. Steam was formerly much used and is still to be found, especially on large machines. Electric shovels are also made but are rarely used on road construction owing to the difficulty in supplying power.

The power shovel is a very efficient excavator when supplied with an adequate battery of wagons, trucks, or railway cars for hauling away its output.

Drag Line.—This machine (Fig. 6-10) is somewhat like a power shovel but differs in that the bucket is operated by cables

FIG. 6-9.—A gasoline power shovel loading a dump wagon pulled by a tractor. All three machines have caterpillar treads.

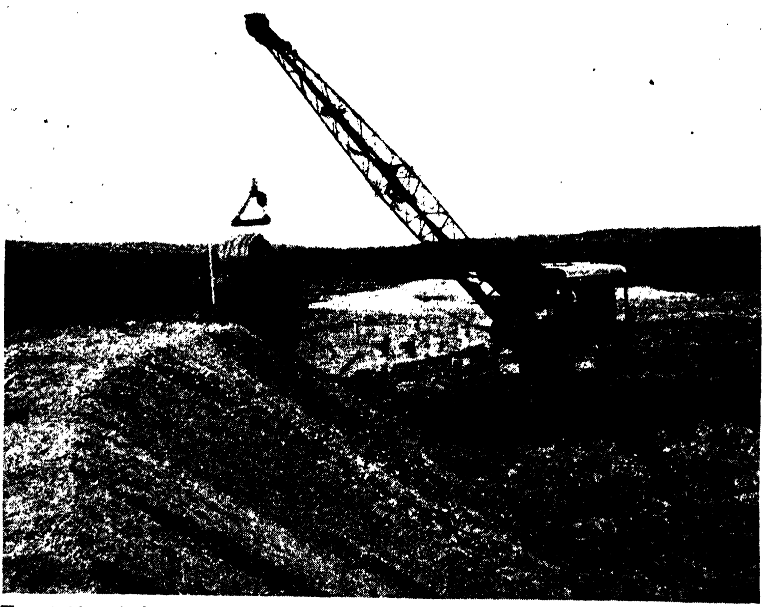


FIG. 6-10.—A drag line excavator building a highway fill from a parallel borrow pit.

instead of a rigid boom or handle. It is especially suitable for throwing up embankments from parallel borrow pits. Such embankments, however, are loose and need special work in compacting, such as water soaking.

Blade Grader.—This implement (Fig. 6-11) is peculiarly adapted to road building. It is unsurpassed for shaping a road where grades are not changed. It is useful in trimming cuts and is indispensable in finishing the top of fills, shoulders, subgrade, side ditches, etc. In addition, it is one of the principal mainte-

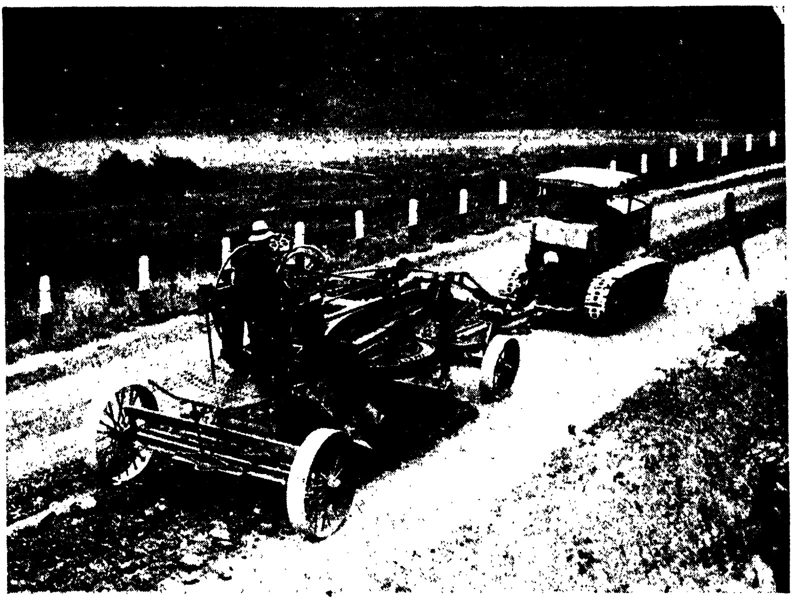


FIG. 6-11.—A blade grader equipped with a scarifier ahead of the blade. The scarifier shown in use.

nance implements for all types of roads. It is made in all sizes from the light one-man patrol grader with a 6-ft. blade to the extra heavy 12-ft. blade machine with *back sloper* for heavy construction work. Many also have a scarifier attachment.

Horses or tractors are used for motive power. For construction work the 10- or 12-ft. size with a 10-ton caterpillar tractor forms an excellent outfit. It will do nearly any work on which a blade can be used and, in addition, is very flexible in its handling and turns in an extremely short space. A *shoulder grader* is a special form of blade grader for shaping the shoulders on paved roads.

A *motor grader* (Fig. 6-12) is a tractor and a blade grader combined into a single machine. Few, if any, motor graders are satisfactory as a primary grading machine, since the traction

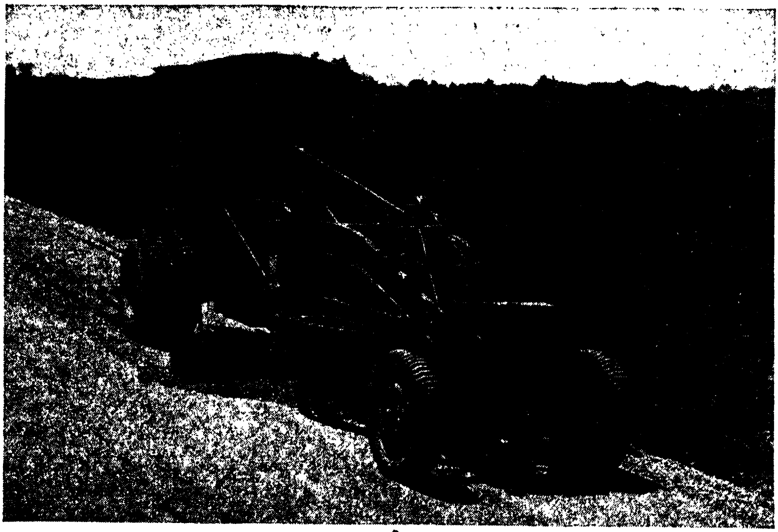


FIG. 6-12.—A motor grader in operation on a gravel road.

FIG. 6-13.—A formgrader in operation. Note the chalk-line and pointer by means of which the cut is made to line and grade.

must be obtained by wheels traveling more or less in the cut. For spreading dirt, finishing the subgrade, mixing and spreading surfacing materials, and for maintenance work these implements are very efficient.

Formgrader.—This machine (Fig. 6-13) consists of a light tractor below which is mounted a rotary cutting blade which cuts a channel to receive the side forms for pavements. The cutting unit is adjustable in position and provided with a pointer which the operator causes to follow a chalk line set at a fixed position with respect to the line and grade of the form.

Subgrader.—The usual form of subgrade machine (Fig. 6-14) consists of a heavy frame mounted on wheels which run on the

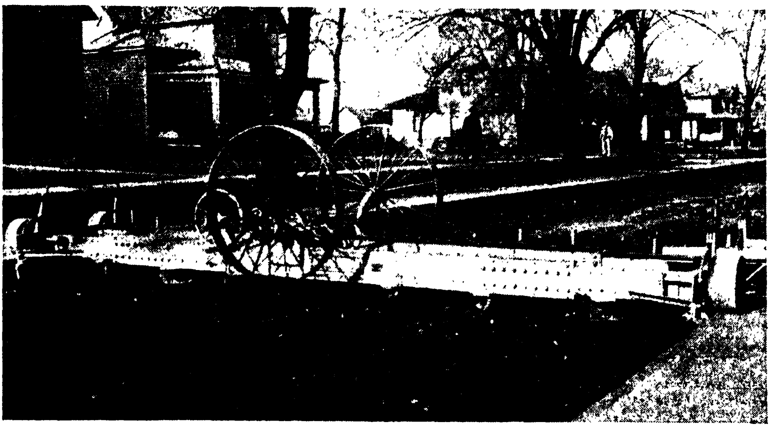


FIG. 6-14.—A subgrader at work between the two side sections of a concrete pavement already placed on a city street.

forms and which carries a series of blades that are adjustable to the shape of the crown. After the forms are set the subgrader trims the subgrade to shape between them. The blades cut the earth to shape and pile the loose material into windrows which are then shoveled out by hand. Such machines are usually pulled by a tractor. Another type of machine has its own power which both moves the machine and operates cutting blades which trim the subgrade and throw the waste outside the forms. Subgrade machines can be used only where the shape of the crown is constant. In intersections and at other places where the crown is warped, hand methods must be used.

Rollers.—Rollers are used for compacting fills, subgrades, pavement surfaces, etc. Hand rollers are used on bedding courses for block pavements and similar light work. Power rollers are built in sizes from 3 to 15 tons for various classes of work.

The *three-wheel* roller is made in the heavier weights for use on fills and macadam. Its three-point suspension gives it greater stability on irregular surfaces and therefore it is preferred for compacting fills. The *tandem* has two wheels with equal width of faces and therefore is better adapted to finishing subgrades and

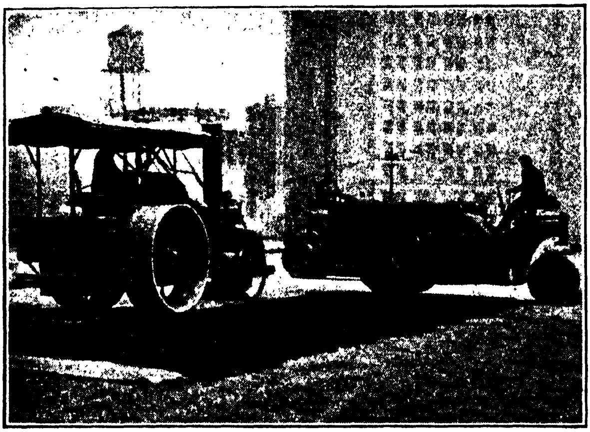


FIG. 6-15.—Three-wheel and tandem rollers on asphalt-pavement construction.

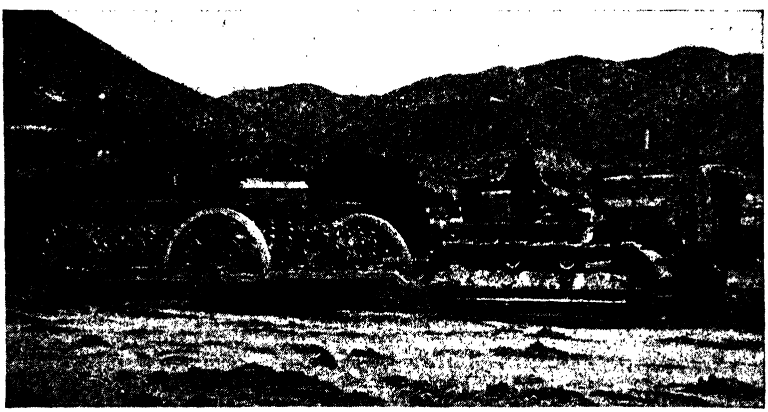


FIG. 6-16.—A sheeps-foot tamper compacting a fill.

compacting bituminous pavements (see Fig. 6-15). The *sheeps-foot tamper* is a form of roller having extension spikes of special shape. As the roller turns, the spikes first penetrate into the soil, compacting it at their ends, and then are withdrawn without loosening the soil. It is used for compacting fills built in thin layers (see Fig. 6-16).

Explosives.[1]—Explosives play a great part in all construction work. They are used for removing stumps, breaking boulders, loosening soil, and breaking solid rock. The economic use of explosives requires care, skill, judgment, and experience. Only in rare cases should explosives be employed without the services of some one experienced in their use.

The principal explosive used in road work is *dynamite*. This is made in several grades, containing from 15 to 70 percent nitroglycerine. The various grades are adapted to different classes of work. Dynamite for roadwork is ordinarily put up in cartridges measuring 1¼ by 8 in. and weighing about ½ lb. It is exploded by a *detonating cap* or *detonator*. Where a single charge is to be fired the fuse-and-cap is satisfactory. If more than one charge is required, as in blasting a cut, they should be fired simultaneously. For this purpose the electric blasting machine and electric detonators or instantaneous fuse between charges should be used.

For blasting stumps the charge should be placed 2 or 3 ft. below the surface, buried in the tap root if one exists. If the roots spread, several charges distributed under the larger roots and fired simultaneously should be used. A rough rule for the amount of explosive is the square of the diameter of the stump in feet is the number of sticks of 20 to 30 percent strength dynamite required.

Boulders may be broken up by placing a charge of 60 to 70 percent dynamite on top and covering it with wet clay. This is called *mud-capping*. One or two pounds of explosive per cubic yard of rock is required depending on the hardness and toughness. *Block-holing, i.e.*, drilling a hole to the center of the boulder, is more effective but requires more labor. From ¼ to ½ lb. of explosive per cubic yard of solid rock is required. *Snakeholing* or drilling holes under the boulder requires from ¾ to 1½ lb. Ledge rock to be excavated should be broken down only by drilling holes and firing simultaneous charges. About 50 percent more explosive per cubic yard of solid rock is needed than for block-holing boulders.

SPECIAL OPERATIONS

New Grading with Blade Grader.—When a new road is to be prepared in country requiring little grade change, there is no

[1] *Cf.* "Modern Road Building and Maintenance" by the Hercules Powder Co. and "Blasters Handbook" by E. I. du Pont de Nemours & Co.

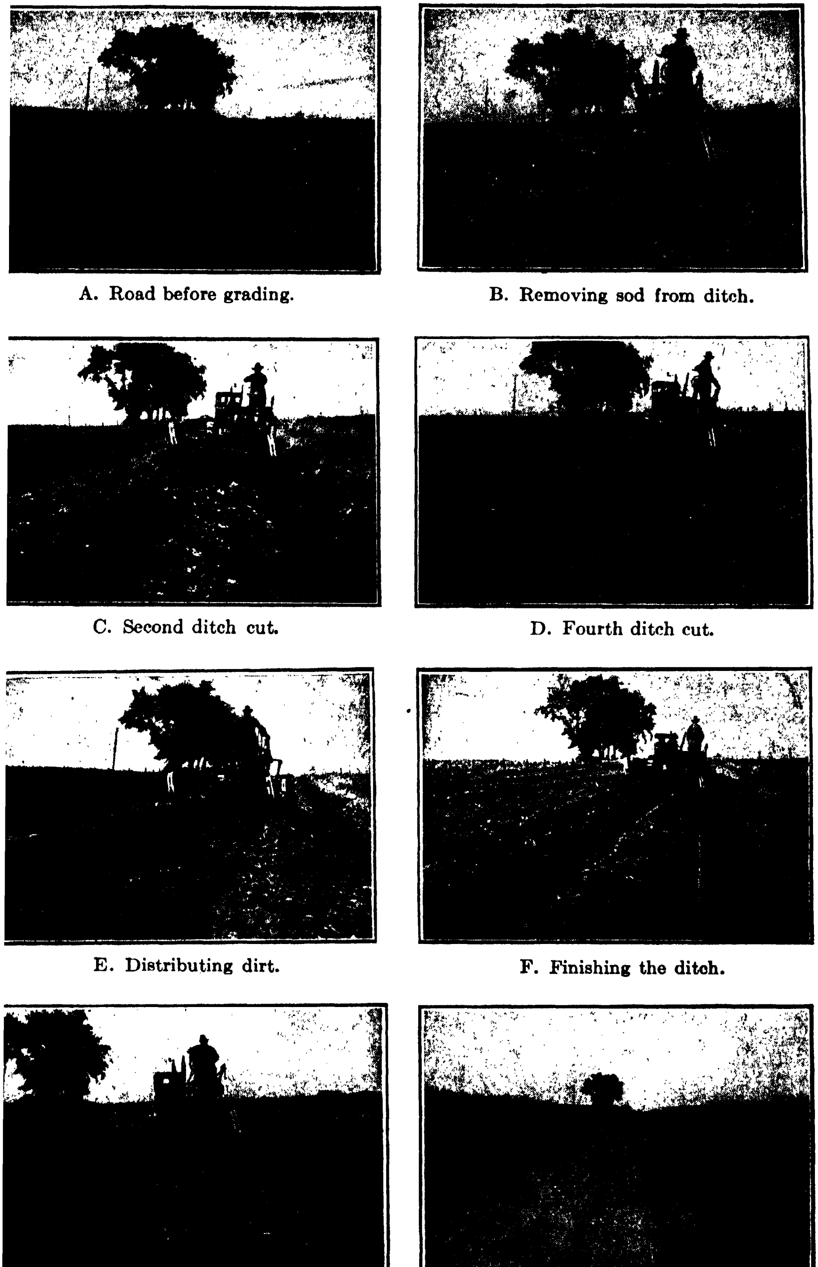
equipment superior to the blade grader. A 12-ft. blade with back-sloper drawn by a caterpillar tractor is best.

The road should first be staked out. Full-length lath set at intervals of 300 or 400 ft. along the center of the ditch to guide the grader man on his first round is all that is necessary. The first cut is made along the ditch line. It should be just deep enough to remove the sod. A second and third ditch cut may be required to remove the sod from the ditch area and distribute it along the shoulder line. Deepening cuts are then made, beginning at the outer edge of the ditch and working toward the shoulder by successive steps and deepening about 6 in. at each cut. The dirt is carried over the sod into the middle of the roadway by successive rounds of the grader. If the ground is covered with sod it is not necessary to strip it from the roadway but chunks of sod should not be brought into the traveled way. If the ditches require more longitudinal slope, this is obtained by lowering the blade or by making short rounds as necessary. Distributing rounds will be required from time to time to distribute the earth brought in from the ditches. This work is continued until the ditch is brought to shape and the traveled way is built up of earth free from sod confined between the ridges of sod. The back sloper is then attached and the outer bank and bottom of the ditch finished. The dirt from this operation is brought into the middle of the road and distributed. The roadway is now ready for use.

This process will usually require about 16 rounds, as follows: 2 to remove the sod, 4 to cut the ditches, 6 to distribute the earth, 2 with the back sloper to finish the ditches, and 2 to finish the surface. The biggest defect in most work is the attempt to do it with too few operations. Under favorable conditions 10 or 12 rounds may suffice while 20 to 25 may be required elsewhere, depending on the soil and the width of roadway. The use of the slip scraper, spades, etc., may be necessary to open outlets for the side ditches, install culverts, etc.

Regrading Old Road.—The regrading of an old road is almost identical with the foregoing except for the number of ditch cuts required since the ditch is already partly excavated. If an entirely new ditch is to be made, the operation becomes the same as for grading a new road.

The road should be staked as before. The sod is cut and placed along the shoulders. The ditch is then deepened and the



A. Road before grading.
B. Removing sod from ditch.
C. Second ditch cut.
D. Fourth ditch cut.
E. Distributing dirt.
F. Finishing the ditch.
G. Finishing the surface.
H. The completed job.

FIG. 6-17.—Regrading earth road with blade grader.

good earth carried into the traveled way. The back slopes and surfaces are finished as before. This work will require from 10 to 16 rounds. Figure 6-17 shows the successive steps in this work and also may be taken as typical of making a new grade.

Finishing Subgrade.—The subgrade for any type of improved surface must be finished true to shape and elevation in order to insure proper thickness of pavement. In addition, it must be as uniform in compactness as possible to give stable support to the slab. If the subgrade is low, more materials are necessary, thus adding to the contractor's cost. If too high, full strength of pavement is not obtained. The preparation of the subgrade involves, first, rough grading, second, fine grading, and, finally, rolling.

The rough grading should be done as close as possible to the finished grade, preferably somewhat above it rather than below. The curbs are then laid, or the side forms set. The fine grading is then done by machine, where such is possible, or else by hand. The hand procedure is nearly always the same. By means of ordinates from strings stretched across the curbs or side forms, spots in the subgrade are cut down at intervals of 5 to 8 ft. each way. These spots are marked with blocks of wood or with paving brick. Workmen with mattocks and shovels under the supervision of a foreman, who should have a good eye for such work, then trim the subgrade to surface between these points.

The subgrade is then rolled. The rolling should be carefully done with roller of only moderate weight. The object is not so much to compact the soil, except where slight fills are made, as to discover soft places, remove waves, and smooth the surface. The roller should preferably weigh about 5 tons. It should always be operated longitudinally and, if the width of roadway will permit, also transversely. Any soft places that show up in the rolling should be dug out and refilled with solid material and well rolled.

After rolling, the surface should be checked, preferably with a template. High places should be cut down and low places filled up and tamped or rolled. The finished subgrade should be such as will give full thickness of pavement at every point, and at no place be more than ¼ to ½ in. low.

A *scratch template* is frequently used to check the subgrade just ahead of the paving. A heavy beam extending across the roadway and traveling on the forms has steel points about 6 in. apart extending downward to the exact elevation of subgrade. This

template is pulled along, frequently by the paving mixer. When a high spot in the subgrade is encountered, the points scratch grooves in the soil indicating where and how much the ground must be cut down.

The cost of finishing the subgrade varies from about 4 to 10 cts. per square yard depending on the soil, methods used, and price of labor. The average in ordinary soils was about 6 to 7 cts. in 1934. Sometimes this cost is carried as a separate item, but often it is included in the price of excavation. In shallow work this latter practice may have a decided effect on the price per cubic yard. For example, if the average cut is 1.2 ft. and the price of finishing the subgrade is 6 cts. per square yard, the cost of finishing amounts to about 15 cts. per cubic yard of excavation.

Backfilling Trenches.—Trenches should be so backfilled that the road surface will not settle. This may be accomplished by using sand, gravel, crushed stone, or concrete or similar materials which are easy to place so as to have little settlement, provided their cost is not excessive. Ordinary earth is often merely tamped into place. This is rarely effective even when the lumps are small and the moisture content is such as to make the soil work the best. Mechanical tampers, however, may give good results. Another method is to flush the trenches with water. This is analogous to the water soaking of fills previously described and in many soils is very effective.

Problems

6-1. The price of excavation is 30 cts. per cubic yard, the free-haul distance 500 ft., and the price of overhaul 2 cts. per yard-station. What is the limit of profitable haul? If a borrow pit furnishing 10,000 cu. yd. costs $800, what would be the additional length of profitable haul to permit the fill to be made from an available cut?

6-2. The total excavation between station 0 and 15 is 5,240 cu. yd. of which 460 is free-haul yardage. The overhaul yardage is moved an average total distance of 880 ft. With other factors as in Prob. 6-1, what are the amount and cost of overhaul and the total cost of the excavation?

6-3. How many cubic yards of cut will be required to make a fill containing 2,880 cu. yd. if the shrinkage factor is 0.6? What will be the amounts with shrinkage factors of 0.9, 1.1, and 1.3?

6-4. A pavement 36 ft. wide between plain curbs has a crown of 3 in., a thickness of 8 in., and a curb height of 7 in. What is the section constant measured from the top of curb?

6-5. In Prob. 6-4 the length is 1,320 ft. and the width of right-of-way 72 ft. Three cross streets have the same width with pavement turnouts 36 ft.

wide with 15-ft. radii at the corners. The average ordinates to top of curb at each station are 0.22, 0.53, 0.90, 0.62, 0.58, 1.00, 1.17, 1.28, 1.10, 0.76, 0.53, 0.33, and 0.25, respectively. What are the area of the pavement, the grand average ordinate, and the total volume of earthwork, exclusive of curb excavation?

6-6. On the street in Probs. 6-4 and 6-5 the outer edges of the sidewalks are 6.0 ft. from the property lines. The average cut from the ground surface to top of curb is 0.9 on one side and 1.2 on the other. What is the amount of parking excavation, making allowance for the cross streets? What will it cost to finish the parkings at 6 cts. per square yard neglecting any cross walks?

6-7. A granite boulder is roughly spherical and about 6 ft. in diameter. How much dynamite will be required to break it up by each of the three common methods?

CHAPTER 7

EARTH ROADS

An earth road is one whose wearing surface is composed of the natural earth.

Since the natural earth may vary through all gradations of soil types, the earth road presents a wide range of characteristics, and specific roads may receive names indicative of the type of soil composing them as *sand* roads, *clay* roads, *loam* roads.

Crown.—Prompt drainage of the surface calls for considerable crown, whereas the requirements of traffic are best met by little or no crown. The correct crown is therefore that which will give efficient drainage with a minimum of conflict with traffic.

Steep crowns cause the road surface to erode into a series of cross gullies, giving a washboard effect extremely objectionable to modern traffic. Steep crowns also cause heavy side thrust on the vehicle equal to 20 lb. per ton of weight for each percent of grade of cross slope. In dry weather, this side thrust causes the road to wear rapidly. The resulting dust piles up in a ridge at the edge of the traveled way and forms an obstruction to drainage. In wet weather when the surface is slippery, this side thrust may cause skidding. To avoid this, traffic seeks the center of the road where it cuts deep ruts which are very difficult to remove and which collect water and permit it to soak into the road. Very flat crowns do not drain readily enough and, in addition, are likely to wear hollow, thus also holding water until the soil is saturated. While this may result in a very muddy road, and possibly an almost impassable one, it is at least free from skidding and therefore is less dangerous.

The proper crown will therefore be such as will maintain drainage and at the same time cause the minimum of skidding and wear. Under fair maintenance the best results are obtained with an average cross slope from center line to edge of ditch of about ½ in. per foot, or a total crown of 7 to 8 in. in a graded way of 30 ft. Under careful maintenance the amount of crown may be reduced to as low as one-half of this value, while twice the

amount may be employed without undue objection. Crowns in excess of 1 in. to the foot are frequently seen but the roads would invariably be better if the crown were reduced below this value (see Table 5-3).

Side Ditches.—The general features of side ditches have been discussed in Chap. 5. It is well, however, to emphasize here the fact that, especially with earth roads, the side ditch should be

FIG. 7-1.—A well-crowned earth road. Note the distribution of traffic.

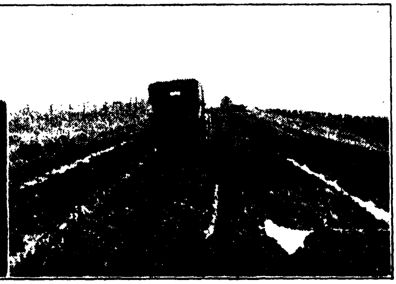


FIG. 7-2.—An undercrowned road. Note the ruts and the indistinct side ditches.

FIG. 7-3.—An overcrowned road Note the ruts in the middle and traffic at the sides.

FIG. 7-4.—Excessive crown, 2.2 in. per foot of width caused by V-leveler. Note the false ditch and the rough middle portion.

shallow and the slope into it comparatively flat so that a car might drive or skid into it with at least a fighting chance to remain upright. The side slope toward the traveled way should be not steeper than 3:1. Back slopes should not exceed 2:1.

Grades.—Earth roads may be built on level grades provided the drainage is satisfactory, as, for example, on long embankments. Maximum grades of almost any value that a vehicle can climb are to be found. Since the tractive resistance of an earth road is comparatively high, the effect of grade is relatively

less and therefore steeper grades may be employed. On the other hand, no type of road is more treacherous than the earth road when wet and consequently if there is any considerable volume of traffic the grade should be reduced if possible to not more than 8 or possibly 10 percent. Since the earth road will be principally employed on the less important highways where the amount of money available is small, it will tend to follow the natural slopes quite closely and consequently will present a grade line full of undulations with many steep slopes.

Construction.—The construction of an earth road involves two steps. First, the building of the subgrade or the making of the necessary cuts and fills and, second, the finishing of the surface.

The first is the same as for any other type of road and is discussed in Chap. 6. The second is very similar to the processes of maintaining an earth road. In fact, finishing of the surface merges imperceptibly into maintenance so that there is no sharp distinction between the two and no definite point at which one may be said to end and the other to commence. For this reason it is customary to consider the road as built when the subgrade is completed and include the finishing of the surface with the maintenance. It should be remembered, however, that construction is not actually completed until the surface is true to shape, smooth, and solid. Once this condition has been obtained, construction is completed and true maintenance begins.

For finishing the surface, a patrol grader and a drag are the principal implements. The grader should be kept at work moving the top soil about so as to fill depressions, remove humps, and especially to bring the surface to the correct crown. The drag should be used after every rain to smooth and puddle the surface and thus consolidate it. Shovels, slip scrapers, etc., may also be required at times to fill holes that develop, shape ditches, and correct any other defects that may appear and cannot be reached with the grader and drag.

Soil Stabilizers.—Some soils are very unstable, easily grinding to dust when dry or quickly turning to mud when wet. Some of these soils may be improved by the addition of coarse material such as sand, screenings, or cinders. Others may be benefited by the incorporation of fine material such as stone dust or portland cement. Still others may be stabilized by the admixture of hydrated lime which tends to flocculate the colloidal clays.

Each particular soil should be studied to determine its needs. Sand soils may be temporarily improved by covering with straw or hay but more permanent results are obtained by the addition of suitable clay or loam.

The best method of application is to pulverize the soil to a depth of about 6 in., spread the proper amount of stabilizer on the surface, and mix the two by harrowing. From 5 to 10 percent by weight of lime, stone dust, or cement is required, or from 2½ to 5 lb. per square yard for a depth of 6 in. The amount of sand or clay is given under sand-clay roads. Stabilizers may prove quite effective, but the cost is likely to be high.

Fig. 7-5.—End of section of heavy soil treated with lime.

MAINTENANCE

Maintenance work on any rural highway may be divided into three parts: (1) maintenance of structures, (2) maintenance of ditches and roadside, and (3) maintenance of surface. The first two are common to all types of roads and are practically independent of the type of surface. The third is entirely a function of the kind of surface and is nearly independent of the other features.

The maintenance of structures includes all repairs, cleaning, painting, etc., of culverts, bridges, retaining walls, directing signs, markers, fences, tile lines, and special structures. In short, it covers the care of all artificial structures on the road other than the surface.

The maintenance of the ditches and roadside includes keeping the ditches clean and their outlets open, the cutting of weeds and removal of debris from the sides of the road, the filling of holes and gullies that may develop, the care of trees and other natural objects retained in the road—in short, the care of everything not included in structures and the surface.

The maintenance of the surface includes all work necessary to keep the surface in the best possible condition for the use of traffic. Maintenance should begin the instant that construction is completed.

Maintenance of the Earth Surface.—Soils change their consistency with changes in the moisture content and consequently

show corresponding changes in their resistance to traffic. When dry, they grind to dust which is stirred up by the vehicles and driven about by the wind or which becomes piled up in ridges by traffic, obstructing drainage. Ruts and depressions may be worn in the surface, making a rough road and interfering with drainage.

When soils are saturated, mud is formed and the surface is quickly cut to pieces by traffic. Unless this condition is remedied before the soil dries out, the surface will be rough when dry and in condition to be further damaged by traffic and rain. With the proper degree of moisture, most soils offer considerable resistance to damage by traffic and, if kept smooth, the earth road is one of the most pleasing surfaces to drive over.

In general, it may be said that the earth surface is frequently and easily disrupted and therefore the maintenance process should be one providing light but frequent repair. The same amount of work distributed in lighter operations at more frequent intervals is vastly more effective than when concentrated in one or two large operations.

Patrol maintenance consists of doing the necessary work of maintenance at frequent intervals as conditions demand. Under this system, work is done continuously and the road is never permitted to become bad.

Gang maintenance or intermittent repairs consists of working the roads at infrequent intervals, usually with heavy equipment since the condition of the road generally makes light equipment ineffective. Under this system the average condition of the road is generally poor. Gang work may be necessary at intervals as an auxiliary to patrol work but can never successfully supplant it.

Cost of Maintenance.—The cost of maintaining earth roads will vary over a very wide range, depending on the amount and kind of work required as well as with soil conditions and methods employed. A road carrying little traffic may possibly be kept in fair condition with an occasional dragging at a cost of less than $10 per mile per year. A more heavily traveled one may require constant and intensive attention at a cost of several hundred dollars per mile. On roads of heavy traffic it is impossible to maintain an earth surface at any cost.

The cost of dragging will vary with the wages paid for a man and team and the number of rounds required. In rural communities contracts can be made for 50 cts. to $1 per mile per

round. For an average road requiring two rounds and about 25 draggings per year, this amounts to $25 to $50 per mile per year for the surface only. The care of the roadside, etc., will cost about an equal amount, making the total cost about $50 to $100 per mile per year. The cost with planers or patrol graders is likely to be somewhat higher.

Patrol maintenance suitable for more heavily traveled roads can be obtained for about $1,200 to $1,600 per year per section. With sections 8 miles long this amounts to $125 to $300 per mile per year, which includes both the surface and the roadside.

MAINTENANCE EQUIPMENT

Drags.—One of the most efficient implements for the maintenance of the earth surface is the drag. The simplest form is the

FIG. 7-6.—Split-log drag.

FIG. 7-7.—Slicker or lap-plank drag.

split-log or *King* drag. It consists of two halves of a log of hard wood, 6 to 8 ft. in length and 8 to 10 in. in diameter, framed together about 3 ft. apart in such a manner that, when dragged along the road at an angle of 45 to 60 deg. with the center line, the rear log will follow directly behind the front one. Usually both logs have the split face vertical and to the front but in friable soils it is often advantageous to reverse the rear log so that the curved portion leads so as to smooth down and compress the surface rather than cut it. To prevent wear, the logs should be shod with iron. The *plank drag* is essentially the same as the split log drag except that sawed planks are used in its construction.

The lap-plank drag or *slicker* consists of three wide, heavy planks bolted together so as to overlap as shown in Fig. 7-7. It is operated much as is the split-log drag. In light friable soils it is quite effective when operated with the edges of the planks to the front and the soil is nearly dry and crumbles readily.

The edges cut slightly and the flat planks press down and smooth the surface. On heavy soils it is best used when the earth is quite wet and plastic and should be run with the edges trailing as shown in Fig. 7-7. It then serves to press down the plastic mud, squeezing the water out of holes and depressions. It is this method of operation that gives it its name of slicker. It is quite effective on such soils early in the spring while the frost is leaving the ground.

Manufactured *steel drags* are on the market. They are usually made with adjustable blades which can be set vertical like the split-log drag or nearly flat like the slicker and hence can be used for both implements. In first cost they are more expensive

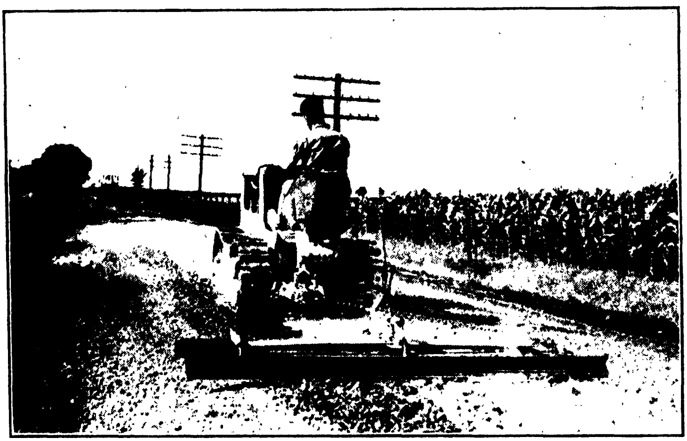


FIG. 7-8.—Steel drag. Pulled by a 2½-ton caterpillar tractor, it is smoothing a road which has been treated with lime.

than the wooden drags and unless oiled and protected when not in use are likely to be shorter in life. They are no more effective than the wooden implements but are more convenient to handle and combine the characteristics of the two types.

Two-way and *three-way* drags are simply two or three drags, usually steel drags, hitched together side by side in such a manner as to cover either half or all of the traveled way at one time. They can be used only when the soil is dry enough to support sufficient motive power to pull them and hence often lose effectiveness on account of not being used when the soil works best. They may give good results if judiciously used but are usually more expensive, both in first cost and in results obtained, than

the simpler types. They are frequently used as smoothers behind V-levelers.

Planers are simply modifications of the drag. The *Minnesota planer* is essentially a plank drag to which runners about 10 ft. long have been attached. These runners serve to keep the blades

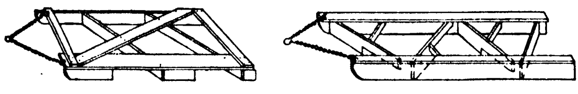


FIG. 7-9.—Road planers.

from dipping into hollows or bouncing over humps as is frequently the fault of the common drag. On the other hand, the runners prevent the tilting of the drag by the shifting of the driver's weight and hence the planer can remove only such irregularities as the long base support permits. On account of its weight it

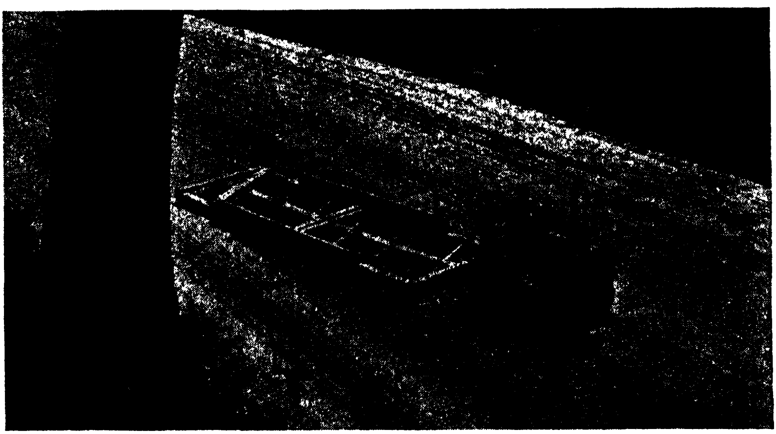


FIG. 7-10.—A large Wisconsin planer pulled by a light tractor.

requires more motive power than the drag and hence may have to be used when the earth is drier. On crumbly soils and on fine gravel it is quite effective.

The *Wisconsin planer* differs from the Minnesota planer in that four blades are used, set in the shape of a *W* so as alternately to move the earth back and forth over the road surface. A notch is made in the three front blades permitting the earth to pass through while the rear blade is set about ½ in. high so that it distributes a little earth evenly over the surface. This gives greater opportunity for the filling of depressions and also

decreases the tendency of building up the crown or leaving a ridge of loose earth in the middle of the road. It is essentially a smoothing tool, the same as the Minnesota planer, and gives good results in crumbly soils or fine gravel.

Dragging.—The drags are best pulled by a two-horse team. A shorter, lighter drag operated with two horses will usually be found superior to a longer and heavier one requiring more power. A light tractor is sometimes used in place of horses but this requires two men to operate the outfit and generally it cannot be used when the soil is at the right consistency to work well.

In operating the drag, the hitch is so made that the drag runs at the desired angle and with both logs or blades bearing evenly on the road. Planks are laid on the cross frames for the driver to stand on. This is partly for his accommodation but mostly for the purpose of putting him where he can control the work of the drag by the judicious shifting of his weight from point to point. If the road surface is in good shape requiring only a little smoothing, he may stand still in the middle of the drag; but if irregularities are present, he can do much to remove them by changing his position. A little thought will indicate the positions which will cause the drag to cut, to discharge its dirt or simply to smooth. A skillful dragman rarely stands still and the results he can obtain in truing a road surface are quite remarkable. Planers are operated much the same as drags, except that the sides or runners make it unnecessary for the driver to ride for the purpose of controlling the work.

Normally, dragging is started at the edge of the traveled way, working the dirt by successive rounds to the middle of the road. This is because the result of both traffic and erosion is to flatten the crown. Persistent operation in this fashion, however, may develop too much crown and therefore the process should be reversed at judicious intervals, working from the center to the side. A fundamental requirement of earth-road maintenance is that the *proper crown must be maintained* and therefore the drag or other equipment must be so operated as to do this rather than in accordance with some arbitrary rules of procedure.

The drag should always be used after a rain and at the time *when the soil works the best.* This varies with the different soils and can only be determined in any particular instance by trial. Some soils work best when plastic but not sticky, and others when nearly dry but crumbly. The object of dragging is to

true up, smooth, and compact the surface; hence the work should be done when these results can be best obtained.

Blade Maintainers.—Blade maintainers may be divided into three classes: (1) patrol graders, (2) motor maintainers, and (3) V-levelers.

The *patrol grader* or *one-man grader* is simply a light blade grader with a blade 6 or 7 ft. in length and with its controls so arranged that it can be driven and handled by one man. Ordinarily it is drawn by a team of horses. A light tractor is sometimes used but this adds a second man to the outfit. As with any

FIG. 7-11.—Patrol grader at work. Note the direction in which the dirt is being moved to preserve the correct crown.

blade grader it must be used when the road is solid enough to support its weight. It is not capable of doing heavy grading work but is used to true up the surface, remove humps and ridges, and fill ruts. If operated frequently, it will keep the surface in excellent shape. In using it, however, care must be taken not to build up the crown but reverse the direction of cut as necessary to maintain the proper cross slopes. While excellent work can be done with the patrol grader alone, a drag is a very useful auxiliary to be used for the purely smoothing operations on the surface where little or no cutting is needed. On roads of fine gravel the patrol grader is an excellent implement for maintenance.

Motor graders have developed out of the attempts to combine as a unit the blade as a maintaining tool and the tractor as the motive power, usually with the idea of one-man control. Owing to their weight and means of traction they can be used only

when the road is sufficiently firm which may be too late to do effective maintenance work on earth roads. Figure 6-12 shows a typical machine of this class. It has a wide range of adjustments and also of speed and can do excellent work. With the scarifier attachment it seems especially adapted to gravel roads. In fact, the motor grader seems to be better adapted to the gravel road than to the earth road.

The *levelers* range in character from a simple log or railroad rail to the heavy complicated V-levelers. The log or rail leveler consists of a piece of log or railroad rail of sufficient length to cover at least half the width of the traveled way. It may be pulled by a team in the same way as a drag. More frequently, however, especially if long, a horse is hitched to each end. It is operated in much the same way as the drag. The rail is superior to the log as, when dragged base foremost, the flange acts as a cutting edge. A 70- to 90-lb. rail about 15 ft. long is the best. A piece of steel channel or I-beam may be used.

FIG. 7-12.—Mud hole near culvert caused by V-leveler.

Another type of leveler consists of a blade or steel beam suspended between the front and rear wheels of a truck. Such an attachment may be homemade. It can be operated only when the road is solid enough to support the truck but in some soils is quite effective.

The *V-leveler* consists of a heavy frame mounted on four wheels and carrying two long, heavy leveling blades supported so as to form a V with the open forward end covering the entire width of the traveled way and with a narrow opening at the apex for the discharge of the excess dirt. Suitable mechanism enables the blades to be swung in and out and to be raised and lowered. A harrow or drag hitched behind the leveler serves to spread out and partially compact the dirt discharged from the blades. A heavy tractor is required to work the machine satisfactorily.

The blades are so regulated as always to keep a small amount of dirt ahead of them, the excess being discharged in a ridge along the center of road through the opening at the apex of the V. The inevitable effect of this is to increase the crown and the

constant use of a V-leveler invariably results in excess crown (see Fig. 7-4). Owing to the method of suspension of the blades it is impossible to draw the points up and in to cross a narrow bridge without a tendency for the heels to depress. The result of this is to form a flat place which does not drain well a short distance ahead of the bridge. At intersections the tendency is to leave the center of the intersection hollow with resulting poor drainage at the very point where it is most needed on account of the concentration of traffic. On the whole the V-leveler is not a satisfactory implement.

Miscellaneous Implements.—Harrows, discs, field rollers, etc., are occasionally used to loosen and level the surface, break clods, or aid in compacting the soil. Regular road rollers are rarely used but at times are of assistance. The combination light roller, scarifier, and blade shown in Fig. 7-13 is useful in finishing

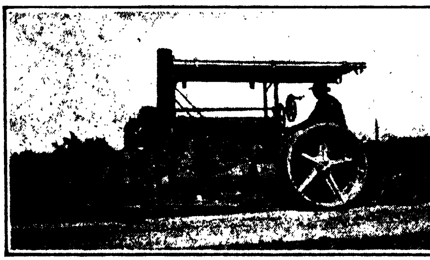


FIG. 7-13.—A combination of light roller, blade grader, and scarifier.

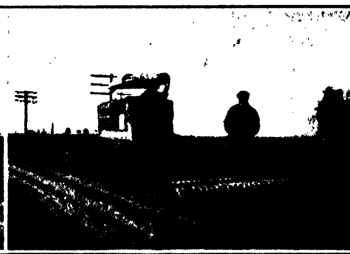


FIG. 7-14.—A double-corrugated farm roller pulverizing clods on a regraded road.

subgrades and earth roads. A scarifier may be especially useful where the soil is too compact to be cut by the blade grader.

SEASONAL MAINTENANCE

Spring.—As soon as the frost starts to leave the ground in the spring, intensive maintenance on the earth road should begin. The ground thaws from both above and below and the final ice sheet to melt is several inches below the surface. Seepage or underdrainage removes the water released below, while that above must be carried away by the side ditches or else evaporate. Furthermore, the freezing and thawing of the soil tend to make it loose and porous and therefore it must be recompacted to make a good road surface.

The slicker on heavy plastic soils and the drag on the lighter soils are perhaps the best implements to work the water to the

surface, where it can run off or evaporate, and at the same time to puddle and compact the surface. If this work is started while the ground is still thawing and is carried on consistently and frequently, the road will dry out smooth and hard far in advance of the one that is permitted to thaw out entirely and is then worked on. If deep ruts have been cut in the road and are holding water, narrow cross trenches cut at the low points will remove the water and greatly hasten the drying.

Another important part of spring maintenance work is the cleaning of side ditches and drainage channels. Much debris is likely to collect during the winter and it is essential that the drainage be prompt and complete in the spring. Especial attention should be paid the removing of all obstructions to the flow of water. At the same time the roadside should be cleaned.

During the spring the work of eradicating the mud holes should begin and this work continued during the summer and fall until completed. Mud holes are almost invariably the result of imperfect drainage. Therefore, the proper way to cure them is to find the defects and remedy them. Some of the causes of mud holes are (1) side ditches without outlets or with clogged outlets, (2) side ditches of too small capacity, (3) springy places in the road needing underdrainage, (4) a broken tile, possibly at some distance from the road, (5) roadway too low, permitting water to cross or stand on the surface, and (6) improper crown. If a mud hole exists, the drainage conditions should be carefully examined and the cause or causes determined and then the proper remedy applied. Above all, attention should be concentrated on the bad places to remove them rather than to expend effort on the good portions of the road to the neglect of the bad. An earth road is no better than its worst mud hole and there is no excuse for any mud hole to exist more than one season.

Summer.—Summer work extends from the time the road is smooth and firm in the spring until intensive work in preparation for the adverse conditions of winter begins. During the summer the soil and air are warm, the ground dries quickly, and traffic is dense with consequent greater wear on the road. Every rain should be made the occasion for dragging. During a prolonged drought, however, little can be done. In fact, dragging is likely to do more damage than good but the instant the drought is broken the drag and blade grader should be set to work reshaping and smoothing the surface.

The early summer is also the proper time to do any heavy grader work such as reshaping the ditches, regrading the surface, or a general regrading, as this offers ample time for the surface to be compacted properly before winter.

Fall.—Fall is the period of preparation for winter. The soil is getting cooler and in many localities rainfall is increasing while traffic is still heavy. Therefore greater attention is needed to keep the surface smooth and firm. There should be no let up in the use of the drag, planer, or blade so that the road may enter winter in the best possible condition. The blade should also be used to trim the shoulders and remove any semblance of an obstruction to the free flow of water from the surface to the ditches. Holes and depressions should receive needed care. Any points where either surface drainage or underdrainage is defective should be given special treatment. As soon as the growing season is over, weeds should be cut from the shoulders, ditches, and roadside and burned. Ditches should be cleared out, outlets of ditches and tile opened, and drift removed from natural channels. In short, in addition to careful attention to the surface, all other parts of the road must be given an overhauling, for the failure of any of these to function properly will be immediately reflected in damage to the surface.


FIG. 7-15.—Sod left in roadway by poor blade grader work.

Winter.—There is a widespread disposition to regard winter as a period of legitmate neglect of the earth road. Although it is impossible to do any effective work on the surface *while frozen*, yet partial or complete thaws may occur several times during the season and each of these can be made the occasion for some effective maintenance. Frequently, such thaws are followed by sharp freezes and an earth road which is well dragged as it commences to freeze will be converted from the roughest of roadways to one of the smoothest. If advantage is taken of each thaw, spring maintenance will be easier and the final thaw will be sure to be covered. During any season the wise maintenance man will watch the daily weather reports, but especially so in winter when a little advance information may be of immense value in doing

effective work. The turning of nature's acts to man's advantage certainly applies to the maintenance of the earth road.

Snow removal is often an important part of winter maintenance. This work is not peculiar to the earth road, however, and, moreover, is likely to be limited to the main roads on account of the cost. It will, therefore, not be discussed here.

Miscellaneous Conditions.—In those localities where freezing does not occur and the year is divided into a wet and a dry season, the seasonal maintenance will consist essentially of the operations given above for spring, summer, and autumn. If there are no marked seasons the work reduces to that of summer maintenance as previously outlined.

In arid regions it may be almost impossible to maintain an earth road in reasonable condition, even under light traffic, since moisture is lacking to make the earth bind together. If there is sufficient humidity in the air, calcium chloride applied to surface may help to stabilize it. Oiling may prove especially effective.

In humid areas the roads may frequently be soft or slippery for long periods. Light applications of sand, pea gravel, etc., may be effective on roads of light traffic where a reasonably good surface must be provided at a minimum of cost. This leads directly to sand-clay, gravel, and similar work on roads of heavier travel. Oiling may also be effective if the soil is reasonably stable when the surface is waterproofed by an oil mat.

In cold regions, where the ground is frozen for long periods, especial care should be taken to have the roads in the best of condition when the freeze-up occurs. Winter maintenance methods should be employed if surface thaws occur, and spring work may be especially important. Since thawing ground is likely to be wet and therefore soft and slippery stabilization of the surface with sand or pea gravel, etc., may be desirable.

OILED EARTH ROADS

The oiling of earth roads developed directly from the accidental spilling of oil on the roads in the oil fields. While it is not definitely known just when or where the first intentional oiling was done, it is quite certain that the practice of oiling earth roads sprang up independently and almost simultaneously in several localities. The greatest development, however, has been in the Middle West with Illinois leading. In that state alone

approximately 45,000,000 gal. of oil have been applied to earth roads each year since about 1920.

At first crude oil or waste oil was spread on the surface, primarily with the idea of laying the dust. It was soon found that the waterproofing qualities were of even greater importance. The mixing process then developed, in which the soil was pulverized to the depth of several inches, oil applied copiously and mixed with the earth by harrowing and then the mixture compacted by rolling. This type of surface gave fair results in localities of moderate rainfall and little or no frost. In other localities, however, it was found to be less effective and considerably more expensive than the simpler surface oiling which is now by far the more common practice.

FIG. 7-16.—An oiled earth road in autumn immediately after 6 days of rain.

Object of Oiling.—The primary object of oiling an earth road is to waterproof the surface. Since the disruption of the earth road is principally due to an excess of water in the soil and since the greater part of the water enters from the surface, it is evident that if the surface is waterproofed the possibility of saturation is greatly reduced and the road will tend to remain in good condition. Oiling, therefore, is a maintenance process and not a type of construction. The surface, however, is essentially a bituminous surface; hence oiled earth road might also be included with the bituminous surface treatments.

Obviously the oiled surface must be of such a character that it will remain intact and not leak for as long a time as possible. It is also evident that the road must be so constructed that water cannot enter from below, or the effect of oiling is destroyed. It is, therefore, essential that the oiled earth *mat* shall be able to withstand the action of traffic, and that it shall be thoroughly waterproof. In addition, the mat must not be so distinct from the soil below as to separate from it, under the action of water, frost, or traffic, since the surface is certain to break up if this occurs. Furthermore, the mat should be of such character that, if accidentally broken or disturbed, it will reunite and compact under traffic. These characteristics are functions of the kind of soil,

the kind of oil, the climate, the traffic, and the process of oiling.

Kind of Oil.—The characteristics of road oil have been discussed in Chap. 3. It is therefore sufficient to say here that the best results on most soils appear to be obtained with residual oils obtained from semiasphaltic crudes which are more or less cracked in the refining and which show a specific viscosity of 20 or more at 60°C. Asphaltic oils such as those from California and Mexico work well on some soils.

Kind of Soil.—Practically all kinds of soils, except sand, can be oiled with more or less success, if thoroughly drained and carefully prepared. Those soils which puddle when wet, which are easily compacted and smoothed, and which offer greatest resistance to water and traffic will always give the best results. Soils which get mucky when wet or that tend to dry out rubbery or porous will not take oil as well. Extra care in preparation, oiling at the proper time, and increased amounts of oil will often give surprising results with these poor soils. The use of stabilizers such as hydrated lime, cement, stone dust, calcium chloride, cinders, or sand have given excellent results in many cases.

Many of the phenomena incident to oiling earth roads have received no explanation. H. F. Winterkorn,[1] however, points out that the application of surface chemistry may offer an explanation and also a method of overcoming the difficulties. Possible developments along this line should be kept in mind.

Time of Oiling.—The oiling may be done at any time after the road has become thoroughly compacted and smooth in the spring. Any attempt to oil a loose spongy road will not be successful. For the conditions of central Illinois the first oiling may be done as early as May, followed by lighter applications in the summer if the traffic is heavy and again in October, in preparation for winter.

Width of Oiled Way.—The width of the oiled way should always be sufficient to pass two vehicles without getting off the oiled surface, except on roads of very sparse traffic. It is customary to oil a width of only about 12 ft. on account of the cost. This width is not sufficient. Traffic runs off and on to the oiled surface, cutting the edges and carrying mud on to the sur-

[1] Oiling Earth Roads—Application of Surface Chemistry, *Ind. Eng. Chem.*, Vol. 26, p. 815, August, 1934.

face. Numerous failures of oiled roads can be traced to these causes. A minimum width of about 8 ft. should be oiled. If considerable traffic uses the road, it should be oiled to a width of at least 16 ft. The oil will not spread out much beyond the width applied so no dependence can be made on this occurring. Road oilers are made so that any width between 4 and 12 ft. can be covered with one trip.

Crown.—The crown of an oiled earth road should be the same as previously indicated for the earth road with a tendency toward the lower rather than the higher values. A careful examination of many miles of both regular and experimental oiled roads has brought the author to the conclusion that the crown of the oiled portion should never exceed ¾ in. per foot and that the best results are obtained with about ½ in. per foot. Indications that higher crown is desirable can usually be traced to inaccuracy in the measurement of the crown employed or more frequently to the attempt to overcome certain faults by increasing the crown rather than by correcting the defects. The most common of these faults is the failure to keep the shoulders outside the oiled area smooth and in condition so that the water will run off. The oiled surface throws more surface water on the shoulders and this must be passed to the ditches promptly. Therefore, vegetation, ridges, ruts, or anything that interferes with rapid drainage must be removed. The oiled way should be kept nearly flat, as indicated, but the shoulder slope may be increased to about 1 in. per foot as it is presumed that traffic will not run on the shoulders. Therefore, the total crown of the graded way may actually be somewhat greater than for an unoiled road.

FIG. 7-17.—Earth shoulder along narrow pavement treated with oil and a light cover of pea gravel. Treated in September, photographed in March.

Amount of oil.—If the road has not been previously oiled, the first application should be about ½ gal. per square yard, preferably applied in two operations of ¼ gal. each 2 to 4 days apart. This may be sufficient for the summer season. The fall application should be about ¼ gal. per square yard. Thus,

for normal conditions, about $\frac{3}{4}$ gal. per square yard per year should be allowed. If the road has been previously oiled and comes through the winter in good condition, the first application may be reduced to $\frac{1}{4}$ to $\frac{3}{8}$ gal. Spongy or porous soils require more oil for even fair results. Not more than $\frac{1}{2}$ gal. per square yard should be applied at one time, however, as the larger quantity runs off instead of penetrating. A total of 1 to $1\frac{1}{2}$ gal. may be required to give the desired result on some soils.

Table 7-1 gives the total gallons of oil required per mile for different rates of application and widths of oiled way.

Preparation of the Road.—The road must be smooth, solid, and free from dust or loose material. Dust prevents the oil from reaching the solid ground and penetrating it. Oiling a loose or poorly compacted road is simply inviting failure. This means that the road must be in the most perfect condition possible when the oil is applied. With continuous patrol maintenance the road should be ready for oiling at almost any time after the spring thaw. If not so maintained, special preparations must be made to secure the same results. If the road is not well shaped, a round or two of a heavy grader may be required to give it the correct crown. This should then be followed by regular patrol work with the patrol grader, drags, or planers, after each rain. This process will probably require one or two months. At the same time special attention must be given to the bad spots. If there are places which hold water, they must be filled. If surface water crosses the road, channels must be provided to carry it away or culverts must be made to carry it under. If underdrainage is needed, it must be put in. If these things are neglected, failure of the oiled earth road is certain. An oiled road as a whole is no better than its worst mud hole, but there is no excuse for a mud hole in an oiled road. If there is any choice between neglecting the preparation of the surface and neglecting the mud holes, it is better to neglect the surface and fix the mud holes. An unoiled road free from mud holes is preferable to a good oiled road interspersed with impassable spots.

The oiling should be timed to take place immediately after a dragging. If this cannot be done and the surface is dusty, the dust should be swept or scraped off so as to apply the oil directly to the solid ground. A patrol grader or a motor grader is very effective for moving the dust. After the oil is applied the

dust may be respread over the oil where it will mix with the oil and compact. Some engineers claim that this is the proper way, and with some soils and oils this may be true but is not sufficiently general to be made the common method. If a rain occurs just as oiling is ready to start, the best thing to do is to wait until the rain is over, then give the surface another dragging, and, as soon as the oil distributor can be run without marring the surface, apply the oil. It is better and far cheaper to pay a few dollars demurrage than to waste a carload of oil by pouring it on a poorly prepared, rough, or wet surface.

Applying the Oil.—Road oil is shipped in tank cars averaging about 8,000 to 10,000 gal. An oil having a specific viscosity

FIG. 7-18.—Applying oil to earth road.

above 10 at 60°C, requires heating before it can be applied. The cars are equipped with heating coils and the oil may be heated by passing steam from any suitable boiler through them. A steam threshing engine is frequently used. This process is rather slow, requiring 12 to 36 hr., so the practice has arisen of blowing steam directly through the oil. This heats the oil rapidly and at the same time stirs it but in addition a considerable amount of water is condensed into and mixed with the oil. This water seems to have no deleterious effect except that allowance must be made for it if a definite amount of oil is to be applied. The amount of water present may amount to as much as 10 percent and is likely to be variable even in the same car.

A more recent device for heating the oil consists of 8 or 10 sections of about 1¼-in. iron pipe 4 to 6 ft. long connected into

a manifold at each end and heated by means of kerosene burners. One manifold is connected to the bottom outlet of the tank car by means of a large hose, and the other to the oil pump. The oil is drawn through the pipes at a rate which permits it to be heated to the desired temperature. This outfit is moderate in price, effective, and economical in operation, and avoids the admixture of water with oil.

The heated oil is pumped by hand or power into distributing tanks which carry it to the road. These tanks carry from 500 to 1,000 gal. at a trip and may be mounted on motor trucks or on horse-drawn wagons. The tendency is toward the 1,000-gal. truck outfit on account of its higher capacity and greater speed in going to and from the road. The tanks are equipped with a pressure distributor mechanism which sprays the oil on to the road in a uniform sheet. The nozzles can be adjusted so that, combined with the running speed of the outfit, any desired amount of oil per unit of area can be evenly and uniformly applied. Care must be taken where one tank load ends and a new one begins to make the junction without leaving a bare spot.

Closing to Traffic.—After the oil has been applied the road should, if possible, be closed to traffic for 2 or 3 days to permit the oil to penetrate. This is very difficult to do as the public seems to resent any curtailment of its privilege of going on any road at any time under any circumstances. In this, people are often most unreasoning and unreasonable, especially with such a simple thing as an oiled earth road. In some cases a simple barricade is sufficient but at times nothing short of a barbed wire entanglement seems to be even remotely effective. Part of the difficulty, however, often lies with the road authorities. *If the road is to be closed, an adequate and clearly marked detour should always be provided.* Nothing is so exasperating to the traveler as to suddenly encounter a barricade and a "road closed" sign without a hint of where to go to get around.

Maintenance of the Oiled Road.—Since the oiling itself is a maintenance project, little or no additional maintenance of the oiled surface should be required. In fact, the less the oiled surface is tampered with the better. The shoulders, however, must be kept smooth to facilitate drainage and the maintenance of the roadside and structures is the same as for any other type of road. The shoulders should therefore be regularly dragged

and kept smooth, the dirt being kept even with but not carried on to the oiled surface and the oiled surface should be disturbed as little as possible. Especially, attention should be given to keep the junction of shoulders and ditch clear so that the water will drain off promptly.

Pot-holes may develop in the oiled surface, usually as the result of a soft spot or of loose material in the surface when the oil was applied. These holes are very difficult and expensive to cure. They can be patched with fair success by cutting out the earth to a depth of about 2 in., tamping in moist soil, and then applying oil at the rate of about ½ gal. per square yard. Good results have also been obtained by pouring in oil to a depth of ½ to 1 in. and then filling the hole with pea gravel with a light cover of fine earth. If the holes are numerous the whole surface should be scarified and recompacted before the next oiling.

An oiled surface can be perpetuated in good condition in the following manner. Every 1 to 3 years the oiled mat is scarified to a depth of 2 to 3 in. The loosened material is next thoroughly pulverized with an ordinary farm disc and reshaped with a blade grader. It is then recompacted by rolling when the soil is slightly moist. An ordinary corrugated farm roller may be used or a regular road roller if one is available. An effective roller can be made of a short section of large corrugated metal pipe filled with concrete. When smooth and firm the surface is reoiled as on new work.

Cost of Oiling.—If it is assumed that the road has been well graded and drained, the cost of oiling will depend on the cost of immediate preparation and the cost of the oil on the road. Usually, the preparation will include the patroling for from 1 to 3 months and the use of the big grader perhaps two rounds or the equivalent. At the present time (1935) this work will average about $40 per mile. For several years, road oil in the Middle West has averaged about 4½ cts. per gallon in tank cars, f.o.b. the siding near the road, with an additional 1 ct. per gallon for heating and applying.

If a road is to be oiled 16 ft. wide with ¾ gal. per square yard, the amount of oil required, from Table 7-1, is 7,040 gal. per mile. At 5½ cts. per gallon, applied, this makes the cost for the oil and its application practically $390 which, with $40 per mile for preparation, makes a total of $430 per mile, which may be taken for an average condition.

TABLE 7-1.—GALLONS OF OIL REQUIRED PER MILE OF ROAD

Gallons per square yard	Width of oiled way, feet						
	8	12	14	16	18	20	24
1/8	587	880	1,027	1,173	1,320	1,467	1,760
1/4	1,173	1,760	2,053	2,347	2,640	2,933	3,520
3/8	1,760	2,640	3,080	3,520	3,960	4,400	5,280
1/2	2,347	3,520	4,107	4,693	5,280	5,867	7,040
5/8	2,933	4,400	5,133	5,867	6,600	7,333	8,800
3/4	3,520	5,280	6,160	7,040	7,920	8,800	10,560
1	4,693	7,000	8,173	9,387	10,560	11,733	14,080
1 1/4	5,867	8,720	10,197	11,733	13,200	14,667	17,600
1 1/2	7,040	10,440	12,200	14,080	15,840	17,600	21,120

Causes of Failure.—The principal causes of failure of the oiled road and the remedies may be enumerated as follows:

1. Spongy soil lacking strength to support the oiled mat under traffic. If due to the type of soil it may possibly be remedied by the use of soil stabilizers or additional oil. If due to inadequate drainage it may be improved only by perfecting the drainage.

2. Side ditches of insufficient capacity, or with inadequate outlets, thus retaining water at high level for long periods of time or permitting it to flow over the surface. The only remedy is improved ditches.

3. The surface not properly shaped, causing puddles to form which gradually break through. Greater care in shaping and compacting the surface is the only cure.

4. Ruts and hollows filled with loose material or the entire surface rough and loose when oil was applied. Proper preparation is the only remedy.

5. Road covered with dust when oiled preventing the penetration of the oil. The dust must be removed before oiling.

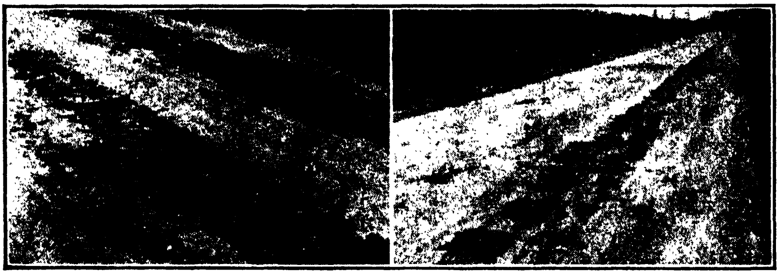
6. Oil of such a character that the oiled mat separated from the base or lacked sufficient cohesion to resist traffic. The only remedy is to use oils that are known to give good results.

7. Insufficient oil. Use the proper amount.

8. Narrow steel tires and tractors with cleats on the wheels.

It is to be noted that more causes of failure can be traced to road conditions than to the oil; consequently the preparation of

the road must never be slighted. A well-prepared road will give comparatively good results with the minimum of oil but it is impossible to make a poor road good with any amount of oil. Since the cost of preparation is 15 percent or less of the total cost, it is evident that it is far better to economize by reducing the oil cost rather than by careless preparation.



Farm tractor with cleats. **Soft dirt in old rut.**

FIG. 7-19.—Failure of oiled earth road.

Characteristics.—A well-oiled earth road has all the good features of the earth road at its best. It is pleasant to travel, of moderate tractive resistance, resilient, and smooth. In addition, it is free from dust and is little affected by ordinary rains. When quite wet, it is somewhat slippery like most bituminous surfaces but it dries quickly. With reasonable care and moderate traffic it may be expected to withstand the winter season with some success, often maintaining a usable surface until reoiled the following year. On the average, 10 to 11 months is its fair normal of perfect service. Its normal traffic capcity can be taken at 200 to 300 vehicles per day.

Problems

7-1. The transverse slopes on two roads are ½ in. and 1¼ in. per foot, respectively. What is the total side thrust in each case on an automobile weighing 3,500 lb.? How much is this per wheel, assuming equal distribution of weight?

7-2. If the total resistance to movement of the car in Prob. 7-1 is 300 lb., what is the tractive force at each rear wheel? How does this compare with the side forces in Prob. 7-1?

7-3. A township has 66 miles of roads. Thirty miles are dragged once a month with one round. Twenty miles are dragged every two weeks with two rounds. The remainder require three rounds every week. If the dragging costs $1 per mile per round, what is the annual dragging bill?

7-4. Exclusive of preparation, what will it cost to oil the system of roads in Prob. 7-3 if the 30 miles are oiled 8 ft. wide with ½ gal. per square yard, the 20 miles with two applications, one of ⅜ gal. and the other ¼ gal. per square yard for a width of 16 ft., and the remainder with one application of ⅜ gal. and two of ¼ gal. per square yard for a width of 21 ft., with oil at 5.5 cts. per gallon applied?

7-5. A village oils 1½ miles of street to a width of 18 ft., ½ mile to a width of 27 ft., and ⅛ mile to a width of 54 ft. How much is required if three applications of ¼ gal. per square yard per season are made?

7-6. If pea gravel costs $1.10 per ton on the siding and 50 cts. per cubic yard to haul and spread, what will be the cost per mile of a cover averaging ⅜ in. thick for a width of 18 ft.?

CHAPTER 8

SAND-CLAY, GRAVEL, AND MACADAM ROADS

SAND-CLAY ROADS

A sand-clay road is one whose traveled way is composed of a layer of sand and clay combined in such proportions as to form a compact, stable mixture. A sand-clay road might well be termed a *clay-mortar* road with the sand acting as the aggregate and the clay as the cementing medium.

Clay.—The clay binder should possess high cohesion, adhesion, stability, and plasticity index combined with low capillarity, elasticity, and shrinkage. For this reason the non-slaking clays and clay loams form the best soils for use in sand-clay construction. Since the sand-clay road is intended to be low in cost, the materials at hand are normally employed even if somewhat inferior in quality, and in most cases reasonably satisfactory results are obtained.

Sand.—The sand at hand is normally used and, therefore, the ideal materials are rarely available. Where there is a choice of sand, a coarse, well-graded, hard-grained material should be selected exactly as for any other mortar.

Proportions.—The best proportions are roughly 1 part of clay to 3 parts of sand but considerable variation is always permissible. Coarse, well-graded sands require less binder than fine sands and plastic clays should be used more sparingly than the more stable varieties. Moreover, the method of proportioning during construction is far from precise, while opportunities always exist for correcting deficiencies in the finished surface. Exact proportioning, therefore, is not necessary. Figure 8-1 shows a gradation chart for sand-clay and gravel roads. A mixture lying within the band marked for sand clay can be expected to yield good results if the plasticity index of the clay is somewhere near the limits shown.

Construction on Sand.—The existing sand road is brought to grade and cross-section with the blade grader. A very flat crown and shallow ditches should be used. Clay is then hauled

on the road and spread in a layer about 3 in. thick and thoroughly mixed with the sand by plowing, harrowing, and discing to a depth of 6 to 8 in. If possible, this should be started when the clay is fairly dry but completed when the road is wet. After the mixing is completed the surface is again shaped with the blade grader and traffic admitted. As with the earth road, construction is not yet completed but careful care of the surface with the blade and drag must be kept up until the mixture is compact and of proper shape. This may require from a few weeks to several months. If sand spots develop, clay is added in small quantities and worked in by the maintenance operations.

Construction on Clay.—The clay road is brought to shape with flat crown and suitable ditches. Sand is then hauled on and incorporated with the clay by harrowing and discing. As more sand must be added than was the case with the clay, progressive hauling and distributing during the discing may prove advantageous. As soon as the mixing is completed, which can best be done when the road is moist, the maintenance processes are started. Clay spots that develop are treated with sand.

Width.—The width of the treated roadway may be either single or double track. If traffic is moderate, funds are limited, and mileage important, a width of about 9 ft. should be used. If the traffic is more frequent, a double-track width of not less than 16 ft. should be used.

Cost.—It is apparent that the cost of a sand-clay road will show a wide range of variation depending on the price of labor and material, the length of haul, the amount of material required, and the difficulty of mixing. For a single-track line where rural prices prevail, the cost may range from about $800 per mile on sand to $1,200 on clay. The cost of wider widths will be practically proportional to the width, since the increase in cost of preparation is relatively small.

Characteristics.—The sand-clay road occupies a position between the earth road and the gravel road. The addition of clean gravel to the sand-clay mixture is all that is necessary to transform it into a gravel type. Since the mixture resists water better than the plain soil, it stands up better than the earth road in wet weather. In dry weather it may wear into ruts and form considerable dust but can be easily reconditioned when again moist. Its riding qualities are essentially those of the earth road.

Maintenance.—Since the mixture is relatively fine grained, the maintenance processes are very similar to those of the earth road. The frequent use of the drag or maintainer when the surface is moist will ordinarily serve to keep the surface in good condition. The motor grader is also very effective for maintenance work since the more stable surface will support the weight of this machine when the material is wet enough to work well. The cost of maintenance is practically the same as for the earth road.

Oiling.—A sand-clay road may be oiled with excellent results. The preparation of the surface and the methods of oiling are exactly the same as for the earth road except that owing to the greater density of the material the oil should be applied in several applications of small quantities so that it will penetrate and not run off. An excellent method is to apply the oil and then add sand or pea gravel at the rate of about 1 cu. yd. to 150 sq. yd. This cover material unites with the oil and soil and forms a mat of high quality.

Modifications.—Stone screenings, chats, cinders, and similar materials may be used in place of sand and give surfaces very similar to the usual sand-clay mixture. In certain localities a natural mixture of sand and clay in roughly the right proportions is found and roads surfaced with this material are often locally termed *top-soil* roads. In other places gypsum is found mixed with the clay, and when this is used in the sand-clay process the road is called a *gypsum* road.

GRAVEL ROADS

A gravel road is one whose traveled way consists of a layer of compacted gravel.

To compact properly a gravel must be graded from fine sand to pebbles and contain a suitable binder. The mixture is then essentially a weak concrete in which the binder and sand form the mortar and the pebbles the coarse aggregate.

The Gravel.—The gravel should be composed of hard, tough, durable rocks to resist the wear of traffic and the action of the elements. It should be well graded in size of particles since a well-graded material makes the binder more effective and produces a more stable mixture. Experience indicates that for satisfactory results under motor traffic the maximum size of pebble in the surface should not exceed ¾ in. and that the

best roads are those with the top composed of pea gravel with a maximum size of 3/8 to 1/2 in. The body of the gravel layer may have stone up to 1 1/2 in., while still larger stones may be permitted in the bottom provided they are well bedded and covered with finer material to a depth of at least 2 in.

The Binder.—Many kinds of binder are found in natural gravels. Stone dust, iron oxide, silica, gypsum, etc., are found to a limited extent and are good binders. Clay, however, is the most common form of binder. Just as in the sand-clay road the clay should possess high cohesion, adhesion, stability, and a high plasticity index combined with low capillarity, elasticity, and shrinkage. The same soils, therefore, that supply suitable binders for sand clay are also satisfactory in gravel road construction.

Composition.—Formerly little attention was given in advance to the composition of the gravel mixture with regard to either the amount or kind of binder or the gradation of the pebbles except to remove large stones. Bank-run gravels were deposited on the road, and if they compacted all was well. If they did not compact, other gravels were sought. Only in rare cases was any attempt made to correct the deficiencies in the first gravel.

Many bank-run gravels contained too much sand so one of the first attempts to improve the gradation was to remove some of the sand. Unfortunately, this led to the practice of trying to build roads with washed gravels. Such gravels contain no binder and therefore never compact until they acquire a binder by the breaking down of soft pebbles, from dirt carried on by traffic, from soil working up from the subgrade, or by having it added artifically. Trying to make a gravel road of washed gravel is like trying to make concrete without cement.

There is a growing appreciation of the importance of proper composition and considerable study has been given this problem, especially since 1930. Figure 8-1 shows a composition chart for sand-clay and gravel roads based on this work. It has been found that mixtures lying within the limits indicated consistently give satisfactory results. It is therefore possible to select materials in advance of the construction of the road with assurance of obtaining good results. It is also possible to improve existing roads by analyzing the materials in place and then correcting the deficiencies by mixing in additional clay, sand, or

pebbles as required. The whole process is very similar to the proportioning of concrete.

Figure 8-2 shows the analyses of four samples taken from an existing gravel road. The curves all lie within the limits shown in Fig. 8-1 except for maximum size of pebble. On the whole, the road was very good. Such defects as did exist were probably

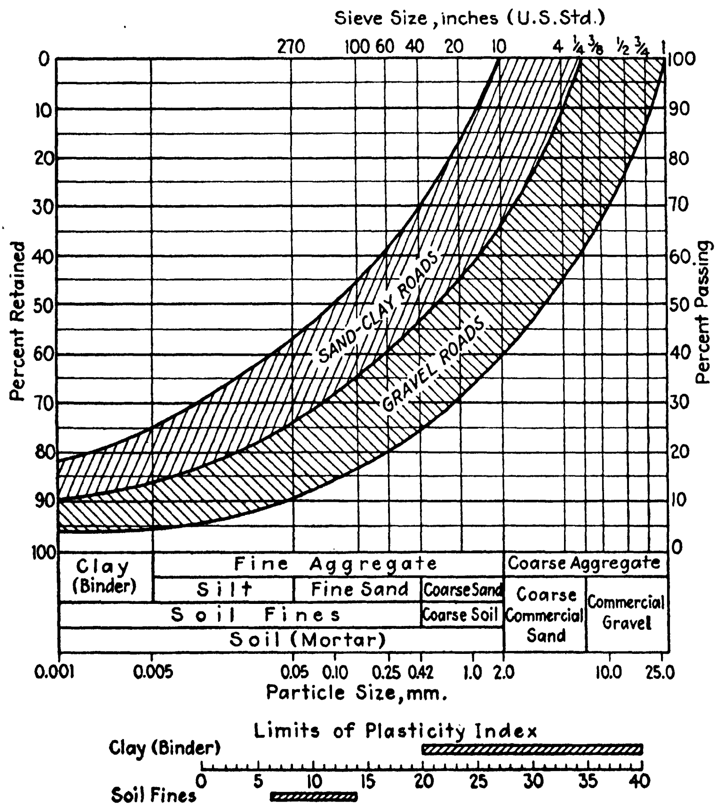


FIG. 8-1.—Composition chart for sand-clay and gravel roads.

due to the characteristics of the clay binder which were little understood at the time the tests were made.

Many times excellent results can be obtained at a considerable saving in cost by using cheap local gravels of somewhat inferior quality in the lower part of the road and then finishing the top with about 2 in. of high-grade but comparatively expensive material. Savings often result even when the thickness of the

local material is increased to compensate for some of its deficiencies.

Stabilization.—This is the process of securing better gravel road mixtures either in new construction or on existing roads. It consists of three parts. First, the improvement of the composition as indicated above, second, the improvement of the binder itself, and, third, the control of the moisture content. A given binder may be improved by the incorporation of calcium chloride, rock salt, hydrated lime, or other materials that modify the character of the clay. The moisture may be controlled by the

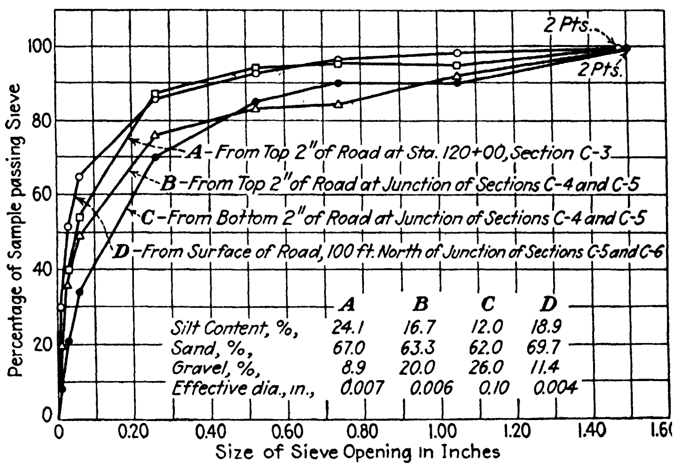


FIG. 8-2.—Analyses of gravel road mixtures. Samples taken from a road built of bank-run gravel after several years of service. (*Ill. Eng. Exp. Sta., Circ.* 18.)

addition of calcium chloride or similar material. Stabilization, therefore, is essentially the application of the principles of making good concrete modified by nature of the cementing medium.

Gradation and Drainage.—It has been frequently noticed that some gravel roads drain off and dry out much more quickly than others. It has usually been assumed that this was due to subgrade or soil conditions. Certain indications lead to the conclusion that the gradation of the gravel and the percentage of silt have a considerable influence on this phenomenon.

It seems quite evident that a gravel road is not entirely impervious but that a greater or less amount of the water falling on the surface penetrates the gravel and drains away by percolation. It is thought that the conditions on a feather-edge road

may be as illustrated in Fig. 8-3. Water falling on the surface penetrates the gravel to the subgrade. If the rate of rainfall is greater than the rate that the water can pass through the gravel, the gravel becomes saturated and the excess water is shed to the sides owing to the crown of the road. If the subgrade is pervious, the water penetrating the gravel passes on down. If impervious, the water is deflected laterally and percolates out at the edge of the gravel. When the rain stops, the water in the gravel con-

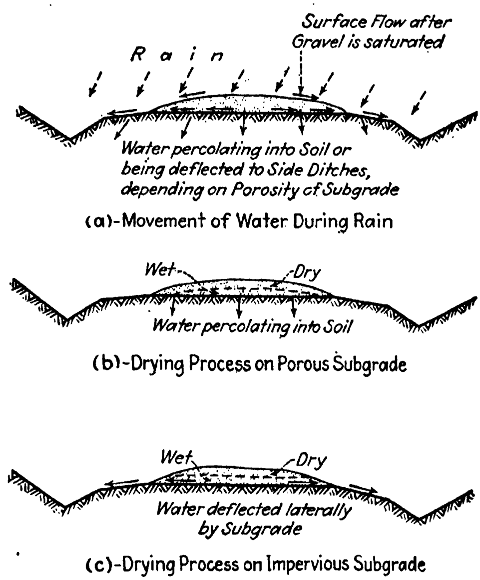


FIG. 8-3.—Drainage through road surface of porous gravel. (*Ill. Eng. Exp. Sta., Circ.* 18.)

tinues to flow out. With a pervious subgrade the entire gravel course dried practically simultaneously, while with the impervious subgrade the center dries quickly while the edges remain wet for some time owing to the water percolating to the sides.

This theory explains why many gravels behave differently when used in trench construction in heavy soils, where lateral flow is prevented by the side of the trench, than when used in feather-edge construction where lateral flow can take place. It also indicates a factor contributing to the change of behavior of some gravels when the top is rendered waterproof by a treatment with bituminous material. It also explains why differences in gradation affect the rate of drying.

The rapidity with which water passes through sand is a function of the gradation of size of particles. Experiments with sand filters indicate that this rate of flow varies with the square of the "mean effective diameter," this diameter being defined as a size such that 10 percent of the material by weight is smaller and 90 percent larger. Some investigations[1] by the author indicate that a gravel containing a sand (up to ¼ in.) whose mean effective diameter is less than about 0.005 in. is likely to be objectionably slow in reaching a reasonable state of dryness.

In apparent contradiction to the foregoing theory comes the report that some of the recent stabilized roads are showing unusually high densities and consequent low porosities. This merely means that the better mixtures are more nearly impervious and therefore less affected by percolating water than the more open types.

Width.—The width of graveled way depends on the amount of traffic. Outlying roads may be single track but with more traffic double or multiple lane widths may be need. For unimportant roads a lane width of 8 ft. may be used but with more or faster traffic the lane width should be 9 or 10 ft. The over-all width will depend somewhat on whether the trench or featheredge type of construction described below is used.

Crown.—The desirable average cross slope is about ⅜ in. per foot. The minimum should not be much under ¼ in. per foot for good drainage, while the maximum should not exceed 1 in. per foot for convenience to traffic and to avoid cross washing from surface water. Table 5-3 gives suitable values for the crown.

Thickness.—No adequate method has been devised for determining the thickness of a gravel road. Approximate rules based on experience are used. If the resulting thickness is not adequate, more gravel is added until the road is satisfactory. For lightweight farm traffic 4 to 6 in. is usually sufficient. Average conditions generally require 6 to 8 in., while for heavy loads or on poor soil 8 to 12 in., or even more, may be necessary. Equation 8-1 or 8-2 for macadam roads may be employed but some excess should be allowed since gravel will not support quite so much load as macadam.

Trench Construction.—After the earthwork necessary to bring the road to the desired grade is completed, a trench is formed

[1] The Construction Rehabilitation and Maintenance of Gravel Roads Suitable for Moderate Traffic, *Circ.* 18, Univ. Illinois Eng. Exp. Sta., 1929.

having the width and depth of the gravel to be placed. This is usually done with the plow and blade grader, the dirt being used to form the shoulders.

The gravel is then hauled in and deposited in the trench. The material should be harrowed or scarified into a uniform condition and the top of the gravel and the shoulders brought to shape with the blade grader. The gravel is best compacted by traffic aided by frequent reshaping with the grader or drag to keep the surface smooth and free from ruts. Experience indicates

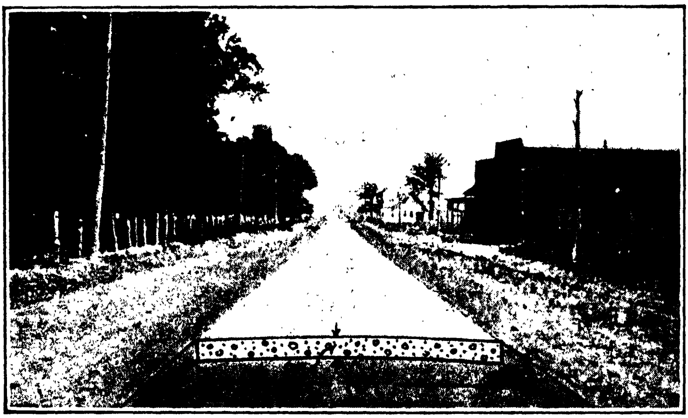


FIG. 8-4.—Trench type.

that rolling will not thoroughly compact the gravel. Apparently a sort of kneading action is required which traffic and blading give but rolling does not.

The road may be built in two or more courses with better results. If an 8- to 12-ton roller is available, the first course is placed, harrowed, and then rolled until firm. The second course is applied in the same way. The top is finished to shape and the entire surface including the shoulders rolled. One roller can cover about 800 to 1,000 ft. of double-track road per day. With a gravel which compacts readily, such as novaculite, this method is especially desirable.

Two-course construction may also be accomplished without a roller. The excess dirt is moved temporarily to the ditches so as to form a shallow trench about one-half the usual depth. Construction then proceeds as if the road were to be only half its final thickness. After the gravel in this course has been consoli-

dated by traffic, the ditches supply dirt to built up the shoulders so as to form a new trench for the second course of gravel, which is applied and compacted in the same manner as the first course.

In trench construction, trouble is sometimes encountered by water collecting in the trenches and softening the subgrade. This may occur during construction, or with porous gravels after the road is finished. This is one of the principal drawbacks to the trench method. Small transverse open ditches or blind drains filled with coarse gravel may be used to overcome this difficulty during construction. They will serve until the gravel is compacted after which they may not be required except with porous gravels, in which case blind drains or tile should be used. Blind drains often become clogged with silt after a few years and become ineffective; hence tile are better.

The trench method is particularly adapted to expensive gravels which compact readily, since it provides a layer of gravel of definite width and thickness, thus preventing waste of material. At the same time it has full depth of material and hence full strength at the edges. It is not so well liked, however, in most localities as the feather-edge method, on account of the higher cost and greater difficulty of construction, the restricted width, and the occasional trouble with drainage.

Feather-edge Construction.—As its name indicates, feather-edge construction permits the gravel to feather out at the sides. In this way, the edges are thinner than the middle, and to maintain the desired thickness under the normal wheel tracks, the total width of gravel must be greater than with the trench type. This requires somewhat more gravel but is compensated by easier construction.

The subgrade is prepared as an earth road with very flat crown. The crown should not exceed about 1/8 in. per foot over that part to be covered with gravel and often is perfectly flat. Outside the limits of the gravel the shoulders should slope from 1/2 to 1 in. per foot. The entire amount of gravel may be deposited at one time or it may be placed in successive increments. In the first case, it is dumped in piles and spread by hand or machine, or spread approximately by regulating the flow from dump trucks or from spreaders pulled by the trucks. It should then be thoroughly loosened with a heavy tooth harrow or a scarifier and shaped with the blade grader. It is then compacted by traffic and blading as previously described for trench construction.

In the second case, about 2 to 3 in. of the gravel is deposited as above. After this layer is compacted, a second addition of 1 to 2 in. is made and this is repeated until the required thickness is built up. This method has the advantages that the gravel may be easily and cheaply spread from piles with the blade grader, the gravel is more thoroughly compacted, and the surface is in better condition throughout the compacting period. Traffic is normally depended on to compact the gravel, but the process can be greatly facilitated by frequent light blading or dragging.

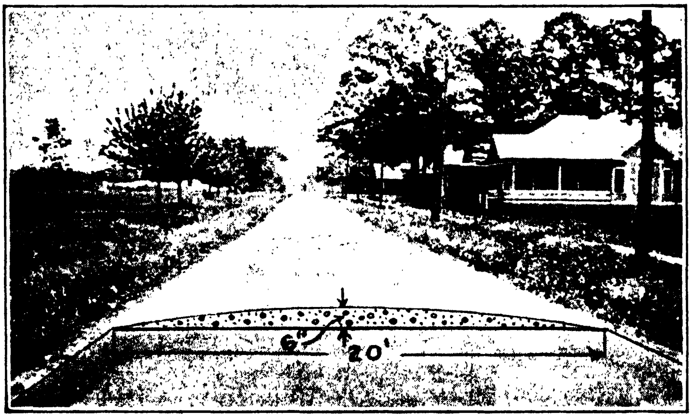


FIG. 8-5.—Feather-edge type.

Sometimes a roller is used but the consensus of opinion is that, in most cases, the results do not warrant the cost.

A convenient method of placing the gravel is to dump it in piles or windrows along one or both edges, or sometimes in the middle of the space to be graveled, and then by means of a blade grader distribute it over the surface. A light cut is taken continuously from the piles and spread over the surface to a depth not exceeding 1 to 2 in. Traffic will soon compact this amount, aided by dragging or blade-grader work. A second application is made in the same way, and so on until the full amount is spread. This procedure requires a longer period of time than to place all the gravel at once, but the total labor is no greater, while the gravel is much better and more uniformly compacted. This method too is especially useful in maintenance and rehabilitation work. Care, however, must be taken in placing the piles and in working the gravel on to the surface not to obstruct the surface

drainage. The feather-edge method is especially adapted to surfacing existing earth roads since the minimum of preparation is required.

Composite Methods.—Combinations of the various methods may be made. Thus the trench method may provide a lower course finished with a feather-edge surface. This combines the advantages of the two systems, especially providing the required thickness at the normal edge. Again, the subgrade may be *dished* giving a feather-edge trench which may be graveled as feather-edge surface. This gives greater wheel-track thickness. Drainage of the trench, however, may need attention, but the

FIG. 8-6.—Spreading gravel with motor grader in feather-edge construction. Note the large stone in this lower course of bank-run gravel.

need for this should be no greater than with regular trench construction.

Mixing Materials.—When two or more materials are used to secure proper composition in the process of stabilization, it is essential that they be thoroughly mixed. This is usually done on the road but may be done in a mixing plant. In trench construction the material requiring the larger quantity should be placed first and the other spread over it. The two are then mixed by harrowing or discing, after which the road is shaped and compacted as before. With feather-edge construction the process is essentially the same. When the road is built up in layers from piles along the side, the two materials can be placed on opposite sides and brought in by the grader. They are then mixed by blading back and forth across the road aided by harrowing and discing.

When the road is to be built of different materials, each in separate courses, as when a local gravel is used for the base and a high-grade gravel for the top, the material for each course is placed and compacted separately without any attempt to mix them together.

Thin Surfaces.—In some localities there exist heavy soils similar to gumbo, which support loads well but become very sticky when wet. These are sometimes improved by applying a thin coat of gravel about 1½ to 2 in. thick for a width of 18 to 20 ft. requiring about 500 cu. yd. per mile. The earth road is first brought to normal crown, and when well compacted the gravel is applied. In a few weeks the gravel partially incorporates with the soil, forming a surface suitable for a moderate amount of light-weight traffic. These surfaces last for 2 to 6 years, after which the process is repeated. Pea gravel seems especially suitable for this work which is more in the nature of stabilizing the soil with gravel than making a gravel road.

Amount of Gravel.—The reduction in volume, due to compacting combined with the loss of material during construction, averages about 20 percent of the compacted volume. The amount of gravel can, therefore, be closely estimated by computing the volume for the given cross-section and length and adding 20 percent.

This amounts to 0.0333 cu. yd. of loose gravel per square yard of surface per inch of compacted thickness, or to 19.555 cu. yd. of loose gravel per mile, per foot of width, per inch of compacted thickness. It is more convenient and sufficiently accurate to use 20 instead of the latter figure. Thus a road 18 ft. wide with an average compacted thickness of 5 in. would require about $18 \times 5 \times 20$ or 1,800 cu. yd. of loose gravel per mile. The average thickness of a feather-edge road with parabolic crown is two-thirds the center-line thickness.

Cost.—The cost of a gravel road depends mostly on the cost of the gravel. The cost of preparing an existing earth road in fair condition for feather-edge surfacing is about the same as preparing the same road for oiling or, at normal prices, about $50 per mile.

Bank-run gravel can sometimes be obtained from local pits for 10 to 20 cts. per cubic yard in the pit. Excavating and loading will cost about the same amount and the hauling 10 to 20 cts. per cubic yard per mile. Thus with a 1-mile haul the

gravel may be dumped on the road at a total cost of 30 to 60 cts. per cubic yard. Assuming a road requiring 2,000 cu. yd. per mile the gravel would cost $600 to $1,200 per mile.

Where the gravel is hauled from commercial gravel plants the pit cost, including excavation and loading, may run from 50 to 75 cts. per cubic yard and the haul is likely to be longer. Assuming a haul of 5 miles at a cost of 15 cts. per cubic yard per mile the gravel for the foregoing road would cost from $2,500 to $3,000 per mile.

Where freight haulage is required the cost may become almost prohibitive. A haul of 50 to 60 miles would be likely to have a freight rate of about 70 cts. per ton or $1.05 per cubic yard. Assuming 10 cts. per cubic yard for unloading, a haul of 5 miles at 15 cts. per mile, and a pit cost of 75 cts., the cost of the gravel for the foregoing road would be increased to $5,300 per mile. When prices like this exist the cost of the road becomes excessive and, considering serviceability and cost of maintenance, the question of substituting a higher type of pavement, even if gravel is adequate, becomes worthy of investigation.

Savings in cost may be affected by combining two materials. Assume that the first gravel mentioned above costs 50 cts. per cubic yard on the road but does not form a good surface although supporting loads fairly well. The third gravel costs $2.65 per cubic yard but is excellent in all respects. The thickness is to be increased about 1 in. to compensate for the poorer gravel. The road will then require about 1,600 cu. yd. of the local gravel and 800 cu. yd. of the outside gravel per mile. The cost of the gravel would then be $1{,}600 \times 0.50 + 800 \times 2.65$ or $2,920. This is a saving of $2,380 over using all outside gravel for a road equally good.

Spreading and compacting by traffic cost from $50 to $100 per mile so that the total cost of the gravel road requiring 2,000 cu. yd. of gravel per mile may vary from $700 to over $5,400 per mile.

Characteristics.—A gravel road in good condition is smooth, somewhat resilient, and pleasing in appearance. It gives good traction and does not become slippery when wet. It tends to soften with continued wet weather, and to become dusty when dry. Frost tends to loosen the gravel and make the surface soft. Its normal average road resistance may be taken as 60 lb. per ton, and its traffic capacity 400 to 600 vehicles per day.

Maintenance.—The maintenance of a gravel road is the same as any other road and includes the care of structures, ditches, roadside, and surface. The first three are practically independent of the type of surface, so only the last requires attention here. The maintenance of the surface consists of keeping the surface smooth, repairing holes, and replacing lost material. It is kept smooth by frequent use of the patrol grader, motor grader, scarifier, drag, or planer. A blade machine, with scarifier attachment, and a drag or planer make a good combination. Motorized equipment may be used to advantage on gravel roads. The best time to use the blade or drag is when the road is wet. The work should start while it is still raining, or immediately after.

Ordinarily simple blade and drag work will be sufficient; but if the surface becomes irregular, the gravel should be scarified to

FIG. 8-7.—Ten minutes' work with a motor grader.

a depth of 3 or 4 in. and then shaped and dragged. The light roller, weighing 4 to 5 tons, appears to help the immediate compacting and may be desirable if the traffic is rather dense.

Holes may be formed by traffic or erosion. If drainage is inadequate, this defect should be first remedied. The surface is then repaired by the addition of gravel. The gravel in and adjacent to the hole should be loosened by picking or scarifying so the new material can unite with it. Care must be taken not to get the gravel too thick so as to form a hump. Frequently a hole may be filled with the gravel adjacent to it. The motor grader is especially efficient at this work as shown by Fig. 8-7.

Material is worn away and lost at a greater or less rate depending largely on the volume and speed of traffic. Under sparse or moderate traffic, little is lost so that new material is needed only at long intervals. Under dense traffic, however, the loss may amount to an inch or more per year. New material is

best added by piling along the edge of the roadway and then spreading with a blade grader as outlined under construction.

Maintenance on light traffic roads will cost about the same as a light traffic earth road. An occasional smoothing with drag, planer, or blade constitutes most of the work at a cost of $25 to $100 per mile per year. With patrol maintenance the cost will run from $125 to $200 per mile, exclusive of new material. On roads carrying dense traffic, maintenance costs become enormous, owing largely to the replacement of lost material. In such cases a gravel road is not economical and should receive some suitable form of surface treatment or be replaced with some type of adequate traffic capacity at the earliest opportunity.

Calcium Chloride.—Excellent results have been obtained in many localities from the use of calcium chloride as a dust preventive and an aid to maintenance. Its function is to retain the necessary amount of moisture in the road so that the clay or other binder retains its effectiveness.

From ½ to 2 lb. per square yard of calcium chloride is applied to the surface by means of a spreader. It takes up water from the road and the air, after which its hygroscopic properties prevent the road from drying out. If too little chloride is used, sufficient moisture is not retained. If too much, the surface tends to become soft and sloppy because of excessive moisture. For this reason, it is better to make an initial application of about 1 lb. per square yard and follow it with half as much once or twice later in the season as may be necessary. With the proper amount, the surface is moist, firm, smooth, dustless, and resistant to traffic. A treatment at 1934 prices will cost from $150 to $300 per mile 18 ft. wide or about 1.5 to 3 cts. per square yard.

Calcium chloride may be incorporated with the gravel in the process of stabilization of either a new or existing road. The exact amount varies with different gravels but averages about 2 lb. per square yard for a thickness of 6 in. In addition to regulating the moisture it may act as a flocculent and improve the character of the clay binder.

Experience seems to indicate that calcium chloride should not be used if a bituminous surface treatment is to be given the gravel. Apparently the retention of moisture causes the bituminous mat to separate from the gravel and ultimately fail under the action of traffic.

Corrugations.—Much difficulty is experienced on some roads with corrugations. These are transverse or nearly transverse waves, sometimes as much as 4 in. in height and 1.5 to 3 ft. apart. This distance between ridges corresponds closely with the harmonic period of automobile springs and tires at normal road speeds. It is probable, therefore, that this harmonic action causes or at least accentuates the corrugation.

Corrugations only occur under fairly dense traffic. Just what starts their formation is not definitely known but the indications are that a soft subgrade, poor grading of the gravel, poor binder, incorrect amount of binder, and moisture all contribute to the

FIG. 8-8.—A raveled and corrugated gravel road. This road could be greatly improved by regrading and stabilization.

problem. Corrugations often appear to start from a simple obstruction such as a stick or stone, or from small holes or erosions, when the road is wet.

Another contributing factor is the maintenance machinery. Certain blade machines are so built that they *chatter* and start slight irregularities. This is aggravated by the common tendency to attempt to make a heavy cut with a light machine. Drags sometimes act similarly. Many sections of road show fresh corrugations at an angle to the roadway corresponding very closely to the direction of the blade of the maintenance machine.

Corrugation can be prevented to a considerable extent by securing greater stability in the gravel, by greater frequency in maintenance operations, and by greater care in the use of main-

tenance machinery. Where once formed they can only be removed by a thorough scarifying, reshaping, and compacting. A heavy roller would probably be an advantage in this work since it would give some initial compacting before traffic had a chance to start new corrugations.

Rehabilitation.—Owing to inadequate maintenance or actual neglect, a gravel road may become very rough and almost unserviceable. Restoring it to good condition may be termed *rehabilitation.* In turn this may be divided into resurfacing and regrading.

Regrading is done without the application of new material. It should begin by a thorough cleaning and reshaping of the

FIG. 8-9.—Scarifying preparatory to regrading.

ditches and shoulders. If the gravel is thick and the crown high, the shoulders should be cut back to permit the spreading of the gravel so as to reduce the crown and increase the width. The gravel should be well scarified and worked to shape with a blade grader and then permitted to recompact. Rolling aids in that it gives an initial firmness, thus preventing the gravel from being scattered and rutted by the first vehicles. This work will require from 8 to 15 rounds of a heavy blade grader and 3 or 4 rounds of a drag, planer, or light grader. An 8-ft. grader pulled by a 5-ton caterpillar tractor is a good outfit. After regrading, light blading or dragging should be kept up until the gravel is compact. The cost will run from $50 to $150 per mile.

Resurfacing.—Resurfacing is similar to regrading except that after the old gravel has been shaped new material is added. From 1 to 6 in. of new material may be needed. It is best applied by distributing it with a blade grader from piles placed along

the edge of the graveled way, in layers of 1 to $1\frac{1}{2}$ in. at a time. Pea gravel is an excellent material to use. The cost is about the same as regrading plus the cost of the new material on the road.

Rehabilitation offers an excellent opportunity for stabilization. Samples of the existing gravel should be analysed and the deficiencies corrected by the addition of the needed material.

Novaculite.—Novaculite gravel is found in the Ozark region, especially in southern Illinois where enormous deposits occur. It consists of silica, clay, and iron oxide. The silica occurs principally in the form of novaculite rock.

It is excellent road material. It bonds quickly, resists wear, and does not produce dust like ordinary gravels. Its pale salmon

Before. After.

Fig. 8-10.—Scarified, regraded, and dressed with $\frac{3}{4}$ in. of pea gravel.

color is very pleasing. Where available, it is an excellent material, but freight rates unfortunately limit its use to a comparatively small area. Its excellent bonding properties have caused it to be hauled several hundred miles to consolidate roads of other gravels that failed to bond.

Roads and streets are often constructed of novaculite essentially by the trench method, using a roller for compacting. The first course is made of very coarse material up to 6 in. in size. These large fragments crush down and bond under a heavy roller. The second course is of 2- to 3-in. material well rolled. The top is then dressed with fine material up to 2 in. in size. The total thickness is 8 to 12 in.

MACADAM

Macadam is a road surface composed of broken stone bound together with stone dust through the action of moisture. For this reason, it is often termed *waterbound* macadam to distinguish it from a similar surface bound with bituminous materials.

Broken stone has been used for roadways from the beginning of civilization. Breaking rock was an early pastime of prisoners and continues so to this day. The Romans used broken stone in connection with their roadwork and other engineering projects. Its first modern use for road building is ascribed to Tresaguet[1] in France. It remained, however, for John L. McAdam[2] and Thomas Telford[2] in England to develop its more scientific use.

McAdam contended that a road of adequate stability could be built entirely of broken stone without the use of a subbase. He built many miles of excellent roadway demonstrating this principle. Power crushers, screens, and rollers were unknown in his day. The rock was broken by hand, while forks similar to the modern potato and stone forks did what little screening was done and no piece weighing over ½ lb. was admitted. The stone was consolidated by traffic. McAdam's method consisted of placing what now would be termed crusher-run stone on the road to a depth of 4 to 5 in. and then admitting traffic. After this course had nearly consolidated, a second course was added and dressed off with fine stone or screenings left by the forks. Traffic combined with maintenance work served to secure a smooth, solid, and nearly impervious surface. Modern practice has substituted power crushers to break the rock, rotary screens to grade the stone, and power rollers to compact it. By proper choice of these implements and suitable materials, the road may be built and compacted ready for traffic without the delay and inconvenience of compacting the stone by traffic. In addition, a more uniform job may be done. The basic idea, that of comparatively small stone cemented by stone dust, persists and the originator's name is perpetuated in the name *macadam.*

Telford admitted the value of fine stone for surfacing but insisted that there should be a base of large stones. This is perpetuated in the *telford base* of today, which is used where heavy loads are common and the subgrade is poor. Telford's construction of the base was practically the same as that of today.

Kind of Stone.—Limestone and the various varieties of trap rock are most generally used for macadam since they are most available and have the required qualities of hardness, toughness, and binding properties. Sandstones lack toughness and do not

[1] About 1764.

[2] McAdam, 1756–1836; Telford, 1757–1834.

bind. Granites are more or less suitable but usually cost more on account of their value as building stone.

Crown.—The crown of a macadam surface may be made somewhat flatter than gravel but slightly greater than for paved surfaces. The normal crown may be taken the same as gravel, about 3⁄8 in. per foot. Table 5-3 gives suitable values.

Width.—Macadam may be made single track of 8 to 10 ft. or double track of 16 to 20 ft. or wider, as conditions demand. Wider widths tend to spread traffic and prevent it from running in lanes, thus tending to reduce rutting.

Thickness.—The thickness of macadam is usually simply chosen and by experience is found to range from 6 to 9 in. with 8 in. perhaps the most common.

The Massachusetts Highway Department early developed the following formula:

$$t = \sqrt{\frac{W}{4p}} \tag{8-1}$$

where t is the thickness in inches, W is the wheel load in pounds, and p is the supporting power of the soil in pounds per square inch.

Harger and Bonney[1] later presented a somewhat more rational formula by including a term T, the width of the tire in inches. Their formula is

$$t = \sqrt{\frac{W}{3p} + \frac{T^2}{9}} - \frac{T}{3} \tag{8-2}$$

In using these formulas an allowance for impact of 50 percent should be added to the static wheel load and the tire width should conform to legal requirements. Assuming a static wheel load of 8,000 lb., a moist clay subgrade with a supporting power of 15 lb. per square inch, (Table 8-1) and a tire width of 10 in., Eq. 8-1 gives a thickness of 14.2 in. and Eq. 8-2 a thickness of 13.4. Values given by these formulas agree closely with those obtained on the Bates test road.[2]

The thickness is often made greater in the middle than at the edge but there is no real reason for this. In fact, there are many

[1] "Handbook for Highway Engineers," McGraw-Hill Book Company, Inc., New York, 1927.

[2] Rational Road Design, *Eng. News Rec.*, Vol. 114, 3, pp. 83–89, Jan. 17, 1935.

of the same reasons for making the edges thicker as there are with concrete. The net result seems to be that a uniform thickness is most economical and satisfactory.

TABLE 8-1.—SAFE BEARING POWER OF SOILS

Kind of material	Safe bearing power	
	Tons per square foot	Pounds per square inch
Hard rock—in thick native beds	200 plus	2,800 plus
Average rock	25 to 30	350 to 425
Poor rock	5 to 10	70 to 140
Clay—dry, hard	6 to 8	80 to 110
Clay—moist, firm	4 to 6	55 to 85
Clay—wet, soft	1 to 2	14 to 30
Sand and gravel, cemented	8 to 10	110 to 140
Sand and gravel, compact	2 to 6	30 to 90
Loam and alluvial soils	0.5 to 1	7 to 15
Silt and quicksand	0 to 0.5	0 to 7

Telford Base.—Where the subgrade is soft the telford base is often used. There seems to be no definite rule when to use it but dependence must be placed upon the engineer's judgment.

The telford base is formed of irregular stone blocks 6 to 8 in. thick and of such size as can be handled easily by one man. They are set in place by hand, tamped to bearing, and the space between carefully filled with smaller stones, spalls, and fine stone or gravel. The base is then rolled with a roller weighing not less than 12 tons. The telford base should be covered with not less than 3 in. of macadam surface.

Number of Courses.—A roller will not thoroughly compact more than about 6 in. of loose stone. Therefore, a macadam pavement should be built in courses requiring this amount or less of stone. For the ordinary thickness two courses approximately equal in thickness are used. For thicker pavement, three courses are used. The first two are laid the same as the base course, the last one forming the finished surface.

Size of Stone.—The size of stone in the top course usually ranges from 1½ to 2½ or 3 in. in size for limestones and ¾ to 1½ in. for hard trap rocks. Screenings for binder should be ½ in. and smaller, except with softer limestones ¾ in. maximum size may be permitted.

Size is somewhat less important in the base course. Frequently the same size as in the top course is used, while sometimes a larger size is permitted. In some cases, with thick pavements, base stone as large as 6 in. is employed.

Subgrade.—The subgrade is prepared and compacted as for any pavement. It is imperative that there be a substantial side support to the stone so that the rolling will compact the stone without spreading it. For this reason a true macadam road is always of trench construction.

On city streets where curbs are provided, these curbs form the side supports and also form reference points for checking the

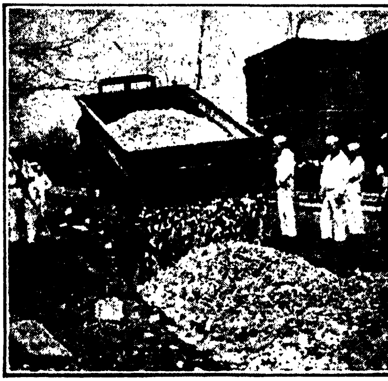


FIG. 8-11.—Dumping stone on subgrade. FIG. 8-12.—Spreading the base course.

thickness and crown. On rural roads this side support must be supplied by firm shoulders. Blind drains may be advisable to keep the trench drained until the stone is compacted. The subgrade should have some crown and, with a uniform thickness of stone, this means the same crown as the surface. The subgrade should be carefully prepared and uniformly but not unduly compacted.

Hauling and Spreading Stone.—Stone may be hauled by wagons, trailer trains, trucks, or industrial railways. It is usually dumped on the subgrade in piles, but some dump trucks are so built as to be capable of spreading the stone almost exactly to the desired thickness. Spreaders to be hitched behind the ordinary dump trucks are also used.

The piled stone may be spread to place by hand with shovels, forks, and ballast rakes or by means of a blade grader. After spreading, it should be harrowed so as to mix the stone thoroughly

and break up any remains of piles so that the course is uniformly loose and consequently will compact evenly.

The correct thickness is obtained by spotting the loads and leveling by eye, by setting blocks of wood of required thickness and spreading stone to correspond and then moving the blocks ahead, by using iron or wooden pegs in the same way, by the use of T's from curbs or grade stakes, or by the use of a template set on the curbs, temporary form boards, or grade stakes. Any of these methods are satisfactory when properly done.

Rolling.—Each course is rolled with a 10- to 15-ton roller weighing 400 to 600 lb. per inch of width of rolls. The lighter roller is suitable for limestone and the latter to trap rock and telford bases. A single roller can compact 50 to 80 sq. yd. per hour.

The rolling should begin at one side, the roller moving back and forth parallel to the side but gradually edging in to the middle. The other half is then rolled in the same way and the process repeated until the stone is firmly compacted. At this stage each fragment should be wedged in the mass so that it can be loosened only with difficulty and individual stones are beginning to break under the roller.

Before rolling the top course the shoulders are trued up with the blade grader and the subsequent rolling extended out on the shoulders 3 or 4 ft. During rolling, especially of the top course, the surface should be carefully watched and any depression filled with stone. Much depends on the skill of the rollerman to secure an even, smooth, well-keyed surface.

Binding.—As soon as the rolling is completed, the screenings are applied. Usually they are dumped in piles along the sides of the roadway and spread by hand with a sweeping motion of the shovel to a depth just sufficient to cover the stone. Mechanical spreaders are sometimes employed.

Rolling is again started, accompanied by light sprinkling and brooming of the surface with fiber brushes or brooms. As the screenings disappear, more are added until no more will be taken up and a small amount remains on the surface. The surface is *puddled* by continuing the rolling and sprinkling, with the addition of screening as required until a mortar or grout of stone dust and water flushes ahead of the roller and the surface takes on an appearance not unlike freshly finished concrete. The road should be closed to traffic for 4 to 7 days. In hot, dry

weather it is desirable to sprinkle daily for 2 or 3 days. Additional rolling, with sprinkling and the addition of screenings, if required, may be given the surface from time to time and aid in further compacting.

Usually only the top course is filled with binder. In some cases for additional strength and especially on soft soils which tend to work up into the stone, the lower course should be filled. This is done the same as for the top course except that the surface is not puddled. The top course should be added as soon as the binder is applied to the lower course.

Amount of Stone.—Broken stone will compact about 20 percent or about the same as gravel. The amount of loose stone can

FIG. 8-13.—Rolling the top course.

FIG. 8-14.—Widening and resurfacing macadam.

therefore be estimated the same as gravel. In placing the stone, allowance must be made for compacting. Thus if the loose stone compacts an amount equal to 20 percent of the compacted thickness, the depth of loose stone must be six-fifths of the compacted thickness.

As stated for gravel, the amount of loose material per inch of compacted thickness is 0.0333 cu. yd. per square yard of surface per inch of thickness or 19.5 cu. yd. per mile per foot of width per inch of thickness. This is practically 27 cu. yd. per 100 ft. of 9-ft. road 8 in. thick. The amount of screenings required is about 20 percent of the thickness of the course to be bonded when the surface is to be puddled and two-thirds to three-fourths as much for unpuddled courses. Since the binder will penetrate about 4 in., the amount of binder is practically the same as the amount of loose stone required for 1 in. of compacted thickness or 0.03333 cu. yd. per square yard of surface or $3\frac{1}{3}$ cu. yd. per 100 ft., 9 ft. wide, for the top course.

Cost.—The cost of macadam will vary with the width, thickness, and the prices of labor and materials. Stone varies considerably in price, owing largely to freight and haulage. Screened stone may vary from about $1 to $3.50 on the road. The cost of spreading, rolling, and binding, including water, is about 60 cts. per cubic yard at a labor level of 40 cts. per hour. This makes the cost per cubic yard in place $1.60 to $4.10. A road 8 in. thick and 18 ft. wide requires 2,810 cu. yd. of stone and 350 cu. yd. of screenings or a total of 3,160 cu. yd. per mile. At these prices, the total cost of the stone surface ranges from about $5,000 to $13,000 per mile, plus the cost of preparing the subgrade, which is comparatively small and may be assumed to be included in the foregoing. This corresponds to a range in price of about 50 cts. to $1.25 per square yard. Owing to this wide range in prices of materials, local quotations should be secured before making even a rough estimate of the cost in any given locality.

Characteristics.—A macadam road in good condition is smooth, somewhat resilient, and gives excellent traction and freedom from skidding. It does not become noticeably slippery when wet but gets dusty when dry.

The surface fails by crushing of the mass owing to insufficient thickness for the type of subgrade, by erosion by wind and water, from the effect of frost, and by the action of traffic. Traffic affects the surface by wear on the stones, removal of the binder, and displacement of the stones. Under horse-drawn, steel-tired vehicles the stone wore into dust faster than carried away so that normally there was always an excess of dust serving as binder except where water sometimes washed it away. Motor traffic, by stirring up air currents, lifts the dust into the air where it is carried away by the wind, leaving the road deficient in binder. Further, the rubber tires do not wear sufficient new dust to replace the loss. With the surface dust gone, the action of motor tires, especially the shearing action of the drive wheels, loosens the dust between the stones and later the stones themselves, causing the road to ravel. This *raveling* may cover large areas leaving the surface covered with loose stones or may result in innumerable pot-holes, either of which is very disagreeable to traffic, destructive to tires, and difficult to repair.

A macadam road is usually assumed to have a traffic capacity of 500 to 700 vehicles per day without excessive maintenance costs.

Maintenance.—Maintenance of a macadam surface consists of preventing raveling by replacing binder and in repairing holes that form or in doing certain operations tending to prevent these failures. Raveling can be cured only by scarifying, recompacting, and rebinding. The simple addition of screenings from time to time as indications of raveling appear may be sufficient to prevent it. Holes may be fixed only by cleaning and then refilling with stone tamped or rolled and covered with screening. They may be prevented the same as raveling. A macadam surface is too hard to be touched by a blade grader or drag but the occasional use of either will serve to keep the binder spread over the surface and prevent raveling.

Frequent sprinkling tends to hold the dust in place and preserve the road but is expensive. Calcium chloride applied at the rate of ½ to 1½ lb. per square yard once or twice a season serves to hold the dust in place by the absorption of moisture and often proves an excellent means of reducing maintenance cost and keeping a good surface, if traffic is not excessive.

Prevention of dust and, indirectly, maintenance of the surface have also been attempted by means of light oils, oil emulsions, and regular road oils. Oiling alone is not very effective or economical but from it has developed the bituminous carpet described in Chap. 11. This surface treatment preserves the macadam by keeping traffic from direct contact with stone. Maintenance work on untreated roads with normal traffic will cost from $50 to $200 per mile per year exclusive of new material Calcium chloride will cost about $250 to $300 per mile 18 ft. wide with an application of 2 lb. per season per square yard. Oiling costs about the same as for an earth road. The cost of bituminous carpets are given in Chap. 11.

Under excessive traffic maintenance, costs of waterbound macadam become enormous, reaching sometimes more than $5,000 per mile per year. In such cases, macadam is absolutely inadequate and should be replaced or else resurfaced with a wearing course that will resist the action of traffic and utilize the macadam to support the loads.

Rehabilitation.—As with gravel, macadam, through neglect or excess wear, may become too thin or too rough for service. Rehabilitation may be accomplished by regrading or resurfacing.

Regrading consists of thoroughly scarifying the surface, reshaping it with a blade grader, and recompacting. Rarely

can this be accomplished without the addition of some new screenings for binder. From 100 to 300 cu. yd. per mile may be required. For a thorough job the rolling, binding, and puddling should be done as on new work. Often this is impossible, in which case the surface is shaped and rolled, then screenings are applied and partially rolled, after which traffic and rain complete the work. The cost will vary with the width, amount of work necessary, amount of new material required, and the cost of labor. Scarifying, reshaping, and rerolling can be done for about $75 to $150 per mile 18 ft. wide, exclusive of new material.

Resurfacing consists in scarifying, reshaping, and rerolling the existing stone similar to a base course. A new surface course from 2 to 4 in. thick is then applied as in new work. The cost of scarifying and reshaping will cost from $50 to $100 per mile 18 ft. wide, while the new surface can be estimated the same as new work.

Traffic-compacted Roads.—In many localities, broken stone roads are constructed much as were the original stone roads of McAdam. Crusher-run stone is applied to the road surface and compacted by traffic, aided by dragging or blade-grader work. This reduces the cost of construction and is economical where stone is cheap. Where stone is expensive, regular macadam construction should be used to receive the full service of the stone.

Such roads may be constructed by the trench method or the feather-edge method, in a manner exactly analogous to the same method of gravel road construction. The stone is less thoroughly compacted than the modern macadam but the roads are suitable for moderate traffic and posses the general characteristics of macadam. Maintenance and rehabilitation are the same as other macadams. The costs are estimated the same as for gravel.

Composite Roads.—Composite construction of gravel and stone is sometimes used. These are nearly always traffic-compacted roads.

Stone-bound gravel is made by using clean screened gravel in place of crushed stone and stone screenings for binder. The gravel is placed and covered with the screenings, after which traffic mixes the two and binds the road. These roads are harder than ordinary gravel but softer than macadam. They may either be trench or feather-edge construction and the cost

is estimated the same as gravel, taking into consideration the two different materials.

Gravel-topped macadam is found in many localities as the result of treating worn or raveling macadam with fine gravel. Sometimes the gravel combines with some of the stone, giving a surface similar to the one just mentioned. More often clay binder is supplied, giving essentially a gravel surface. Pea gravel containing binder is best for this work. There is some evidence that such a surface is easier to maintain than macadam, while it possesses the load capacity of macadam. The old macadam should be scarified and reshaped and a fine gravel suitable for gravel road surface applied to a depth of 1 to 1½ in. Maintenance is the same as for gravel.

Cement-bound macadam is a misnomer applied to a layer of one-size stone impregnated with a grout composed of portland cement, sand, and water. This form of construction should properly be classified as a kind of concrete and is, therefore, included in Chap. 9.

Problems

8-1. Compute the amount of gravel per mile for a trench-type road 20 ft. wide and 9 in. compacted thickness. How many carloads would this be?

8-2. Compute the amount of gravel per mile for a feather-edge road 12 ft. wide and 6 in. compacted thickness. How many carloads would this be?

8-3. Compute the amount of pea gravel per mile for a top dressing ¾ in. thick on a road 24 ft. wide. What will it cost if the plant price is 50 cts. per ton, the freight rate 66 cts. per ton, and the cost of unloading, hauling, and spreading is 60 cts. per cubic yard?

8-4. Write specifications for a road gravel to conform to the limits set in Fig. 8-1 using a maximum size of ¾ in.

8-5. Compute the thickness for a macadam road for a wheel load of 8,000 lb. on a soil capable of supporting 4 tons per square foot.

8-6. Make a bill of material for a macadam road 3 miles long, 20 ft. wide, and 8 in. thick to be built in two equal courses, the top course only to be bound and puddled.

8-7. What will be the cost of the materials in Prob. 8-6 if the stone weighs 105 lb. per cubic foot, the plant price is 75 cts. per ton, the freight rate is 60 cts. unloading, hauling, and spreading is 50 cts. per cubic yard, and the rolling and binding, including water, is 65 cts. per cubic yard of compacted stone?

8-8. Estimate the cost per season of treating 5 miles of road 24 ft. wide with calcium chloride at $26 per ton delivered on the road.

CHAPTER 9

CONCRETE PAVEMENTS AND PAVEMENT BASES

PAVEMENTS

A concrete pavement is one consisting of a monolithic slab of portland-cement concrete[1] which serves both as the load-carrying unit and as the wearing surface.

A *two-course* concrete pavement is composed of two courses of different composition. The lower course is made of a somewhat lean mix using ordinary aggregates. The upper or wearing course has a much richer mix containing selected aggregates. The top course is placed before the bottom one has set, so that the two combine into a monolithic slab.

A *one-course* concrete pavement is homogeneous from top to bottom. If unreinforced, or if containing only dowel bars, it is laid in a single operation. If mesh or mat reinforcement is used, the slab is laid in two operations almost exactly like the two-course pavement except for the proportions. The one-course has practically superseded the two-course type.

Quality of Concrete.—Since the slab must carry the load and also take the wear of traffic, the concrete must be of the best quality. The compressive strength should be not less than 4,000 lb. per square inch at 28 days, and 4,500 lb. per square inch is not hard to obtain. Wear blocks tested in a Talbot-Jones rattler at the age of 28 days should show a wear of not more than about 3/8 in. The modulus of rupture of 6- by 6-in. beams, molded and cured on the site, should be not less than 800 lb. per square inch at 28 days (A.S.T.M. D366-33T).

Proportions.—The more scientific methods of proportioning the concrete as outlined in Chap. 4 are rapidly displacing the purely arbitrary methods in common use a few years ago. On the other hand, nominal proportions often form the basis of more exact methods and occasionally are necessary in emergency or repair work.

[1] The first portland-cement concrete pavement was laid in Bellefontaine, Ohio, in 1893.

For one-course pavements the ordinary proportions range from about 1:1¾:2½ to 1:2½:4, with 1:2:3 the most common for hand-compacting methods and 1:2:3½ for machine compacting. Two-course work may range from 1:2½:4 in the lower part to 1:1½:2 in the top.

Fast-hardening concrete may be made either by using special high-speed cements in the regular proportions or by using richer mixes with standard portland cement. In the latter case the cement content is usually increased about 50 percent, changing the 1:2:3½ to a 1:1⅓:2⅓ mix. These mixes will gain strength roughly twice as fast as the normal mixes.

Consistency.—Much greater attention is being paid to the consistency of the concrete in order to obtain maximum strength and the best workmanship. The consistency should always be the driest that can be placed and finished with the greatest efficiency. Hand shaping and compacting require a somewhat softer concrete than does machine work, and hot weather requires more water than cool weather. The normal slump is about 1 to 2 in. for machine work, and 2 to 3 in. for hand work. The water content will range from 5 to 6½ gal. per sack of cement, including the surface moisture in the aggregates.

Construction Procedure.—The construction of any concrete pavement involves the following steps:

1. Placing forms and finishing subgrade.
2. Proportioning.
3. Mixing.
4. Placing.
5. Shaping and compacting.
6. Finishing.
7. Protecting and curing.

Forms.—Side forms are necessary to hold the concrete in place and to provide guides for shaping and finishing the surface. *Steel forms* should be used to give adequate support and traction to a finishing machine. *Wood forms* may be used for hand-compacting methods and are almost imperative in making short-radius curves. They are sometimes used with finishing machines where steel forms cannot be placed.

The forms are placed when the *rough grading* (see Chap. 6) is completed and the *fine grading* or finishing of the subgrade is done between them. A *formgrader* (Fig. 6-13) is frequently used to cut a trench to the proper profile to receive the forms. On rural

roads the slab is usually built between suitable removable forms, and curbs or gutters, if any, added later. On city streets it is common practice to build the curbs or gutters first and then use them as the forms for the slab. Frequently, however, curb-and-gutter is placed at the sides, a middle strip built with forms and a finishing machine, and the space between filled in by hand methods. This is satisfactory with present-day flat crowns.

The smoothness of the pavement depends a great deal on the vertical accuracy and firmness of the forms. Steel forms are permitted a variation not greater than the thickness of a hacksaw blade (about $\frac{1}{32}$ in.) in 10 ft. Wood forms cannot be set so accurately, but a variation of not more than $\frac{1}{8}$ in. in 10 ft. can easily be attained.

All forms should be well oiled just before the concrete is placed so that the concrete will not stick to them and make removal difficult with the attendant danger of bending the forms when prying them loose. A cheap grade of heavy oil commonly called *black oil* is generally used.

Proportioning.—Proportioning includes the selection of the basic proportions, the modification of these proportions to meet variations in materials or conditions, and the measurement of the required amount of materials into batches for mixing. All of these are treated in Chap. 4.

The best practice now stations a *proportioning engineer* at the batching plant whose duties are to inspect the materials for quality, make frequent tests of the aggregates for gradation and moisture content, modify the proportions in accordance with these tests, and check the measurement of the materials into batches. His work is greatly facilitated by the use of weighing devices for the aggregates and accurate measuring equipment for the water.

Mixing.—Pavement concrete is always mixed in a batch mixer (see Chap. 4). The normal mixing time is 1 min. for regular mixes, but 2 min. or more may be used for high-early-strength or fast-hardening concretes.

With a *central mixing plant* the unloading facilities, stock piles, cement sheds, measuring equipment, mixer, etc., are located at a convenient point. The batchers feed directly into the mixer which discharges the concrete into trucks or industrial railway cars for haulage to the road. This method has the advantages that all of the operations of proportioning and mixing are con-

centrated at one place and a simple type of mixer can be used. Its disadvantages are (1) the haulage system has greater weight to handle; (2) the concrete tends to compact or to segregate while on the way, making it more difficult to place; (3) it cannot be dumped on the subgrade in convenient piles for spreading; (4) with mesh reinforcement and truck haulage the trucks must back over the first layer containing the mesh to dump the second layer and thus bend and displace the mesh. In spite of these difficulties *wet haulage* has been successfully used on hauls as long as 8 miles.

In general, however, the central mixing plant is better adapted to city work where existing pavements and numerous intersections are in its favor than it is on rural roads where the distances are comparatively long and generally over poor roadways.

With a *central proportioning plant* the equipment at the plant is the same except that there is no mixer. The mixer is of the automotive type and does its work at the point of laying the concrete. The aggregates for each batch are measured and loaded into trucks or cars and hauled dry to the mixer. The cement is added at the plant or at any point between it and the mixer as is most convenient. Water is supplied to the mixer through a pipe line. The mixed concrete is discharged into a bucket suspended from a trolley traveling on a boom extending from the mixer in such a way that the mixer operator can drop the concrete so nearly into the required place that comparatively little work is required to spread it into place.

A six-bag (28-E) mixer is generally used. The rate of laying the pavement is controlled by the output of the mixer rather than by the capacity of the gang to place and finish the concrete. Constant efforts are therefore being made to increase the mixer capacity. Reduced mixing time has not proved satisfactory. Larger mixers are expensive and often clumsy. Some attempts have been made to run two ordinary mixers in *tandem*. Each batch is partially mixed in the leading mixer and then transferred to the second mixer where the mixing is completed while a fresh batch is being started in the first machine. In this way the lost time in loading and discharging can be reduced and a corresponding increase in capacity obtained.

There has been a limited use of *transit mixers* which consist of mixing drums mounted on motor trucks. They are charged at a batching plant and mix the concrete while the trucks are traveling to their destinations. They do good work but their cost is high.

It would seem that their proper field is the distribution of ready-mixed concrete in cities and repair work on roads and streets where the amount of concrete required at one place is not large and where the points are scattered and at variable distances.

Haulage.—Adequate and efficient haulage from the plant to the road is essential to economic and rapid construction. The industrial railway is adapted to localities where the grades are less than about 3 percent, and it has the advantage that it does not disturb the finished subgrade since the track can be laid on a narrow shoulder. Trucks can serve any grade on which a pavement is likely to be built but are at a disadvantage on soft or wet ground. The general practice has been to run the mixer between the forms; hence the trucks had to travel on the subgrade to reach the mixer. This often resulted in a rutted subgrade very difficult to reshape satisfactorily to receive the concrete. During recent years the tendency has been toward shoulders 10 ft. and more in width which make it possible to run the mixer on the shoulder and keep all of the haulage off the subgrade.

Subgrade Storage.—Formerly all paving work was done by piling the materials on the finished subgrade in advance of the mixing. The hauling could be done when the subgrade was firm, thus causing little damage. The materials were picked up from the piles with shovels, measured in wheelbarrows or boxes, and transferred to the mixer by wheelbarrow or belt conveyor.

This method was objected to on account of the danger of mixing dirt with the materials, inaccuracy of measurement, low capacity, and the resulting high cost. By placing a thin layer of sand under the stone the latter can be picked up clean with a little care, nor need there be any dirt taken up with the fine aggregate. The limited capacity, however, has caused it to give way to those of greater output. For small jobs in isolated locations this method is still available and with a little care can be made entirely satisfactory.

Placing.—Placing involves all of the operations necessary to put the mixed concrete into place ready for shaping, compacting, and finishing. It includes the installation of center joints, reinforcing, dowels, expansion and contraction joints, and all other details that must be provided at the time the concrete is placed. The special features of installing these accessories are included with the discussion of the accessories themselves.

The concrete is dumped on to the subgrade from the trucks, cars, or mixer bucket. The *puddlers* then spread it approximately to required depth and shape immediately in front of the shaping and compacting equipment. With hand shaping the concrete must be spread more accurately than with machine shaping since the machine can push a considerable ridge of concrete ahead of it. When mesh reinforcement is used, a layer of concrete is first spread and leveled to such a depth as will bring the reinforcement to the desired elevation in the slab. The reinforcement is then set in place and covered with concrete to the full depth of slab.

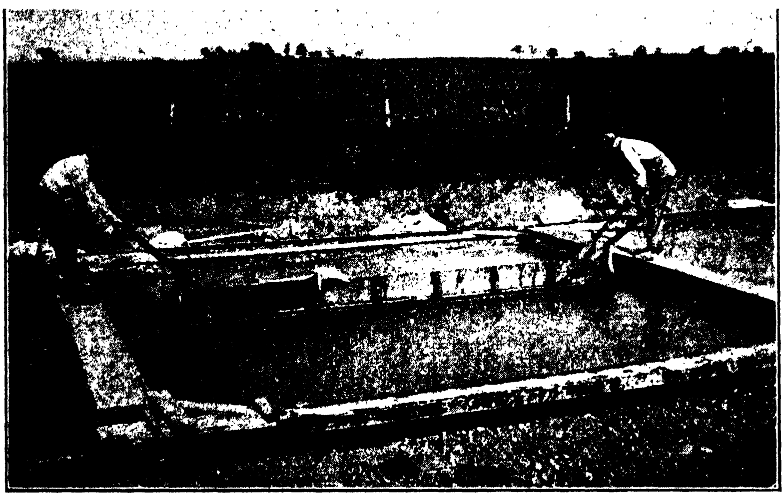


FIG. 9-1.—A longitudinal float used to correct transverse waves left by the strike board. The strike board is similar in design but is curved to the crown of the pavement and is used transversely to shape and compact the concrete.

Care must be taken to embed all bars thoroughly and to puddle the concrete along the forms, center joints, transverse joints, in corners, and at other places where voids or *honeycomb* is likely to occur.

Hand Shaping and Compacting.—The first step is *striking* the concrete to shape with a *template* or *strike board.* This is similar to the longitudinal float shown in Fig. 9-1 except that it is arched to the crown of the roadway. Its length is about 2 ft. more than the width of pavement. It is operated with a tamping and a rubbing motion, used alternately. For tamping it is raised slightly and dropped, a forward movement of a few inches being made with each blow. For smoothing, it is used with a back-

and-forth motion across the pavement, at the same time advancing slowing. These actions are repeated until the concrete has proper shape and is partly compacted.

The next step is usually *rolling* although this is sometimes omitted. Either the *Macon roller* (Fig. 9-2), which is a smooth cylinder of sheet iron, or the *perforated roller*, which is a cylinder of heavy wire mesh with about ¾-in. openings, may be used but the latter is probably the better since the wires push the aggregate down while the spaces between them permit the

FIG. 9-2.—The Macon roller.

escape of entrained air. Either type is pulled across the pavement from edge to edge, advancing about half its length at each trip. One or two rollings are generally sufficient to complete the compacting of the concrete and help remove the excess mixing water. The template should then be used again with a rubbing motion to correct any distortion of the crown caused by the rolling.

Following the rolling the surface is trued longitudinally by means of a *longitudinal float* (Fig. 9-1) sometimes called a *bull float*. This float is similar to the strike board except that it is straight instead of crowned. It may be made of wood or metal and is generally 12 to 15 ft. long. Two men operate this float from a pair of *movable bridges* arranged to travel on the side forms. Beginning at one edge of the slab the float is pulled back and forth longitudinally with a stroke of about a foot while it is

moved laterally a few inches with each stroke until the full width of pavement is covered. The bridges are then moved ahead about half the length of the float, and the process repeated. Generally one, or sometimes two, passes of the float suffice to rub out the small transverse waves left by the strike board.

The next step is the use of the *straightedge.* This implement is 10 ft. long, preferably made of metal, and provided with a handle long enough to reach to the middle of the pavement. It is applied parallel to the center line and at frequent enough intervals to detect any humps and hollows. Small irregularities may be removed with the straightedge but larger ones are corrected by

A *B*

FIG. 9-3.—*A*, hand floats; *B*, long-handled floats.

adding or removing concrete as required, smoothing the surface with a *long-handled float,* and rechecking with the straightedge.

At intersections, railroad crossings, etc., where the surface is warped from its normal shape the strike board cannot be used. Dependence must be placed on the long-handled float and the roller for shaping and compacting. Under the same conditions, and also on sharp vertical curves, the straightedge cannot be used except by making allowance for the required variance in its length.

Machine Shaping and Compacting.—In this method the strike board and roller are replaced by a special machine commonly called a *finishing machine.* This name originated because the first machines actually did the finishing, but now their functions are only those of shaping and compacting.

A finishing machine (Fig. 9-4) consists of two *screeds* or combined strike boards and floats, driven by power and mounted on a heavy frame equipped with wheels to run on the forms. The power unit, generally a gasoline engine, also supplies traction.

The screeds are about 10 in. wide, 2 ft. longer than the width of slab, and adjustable to the crown of pavement. They are spaced about 6 ft. apart.

When in operation the screeds rest on the forms and move back and forth about thirty times per minute while the whole machine slowly advances. They cut the concrete to shape, pushing the excess ahead, and compact that in place by the combined action of their weight and motion. After a forward run is made, the screeds are raised and the machine backed the desired distance for another run. Usually two or three trips over the same

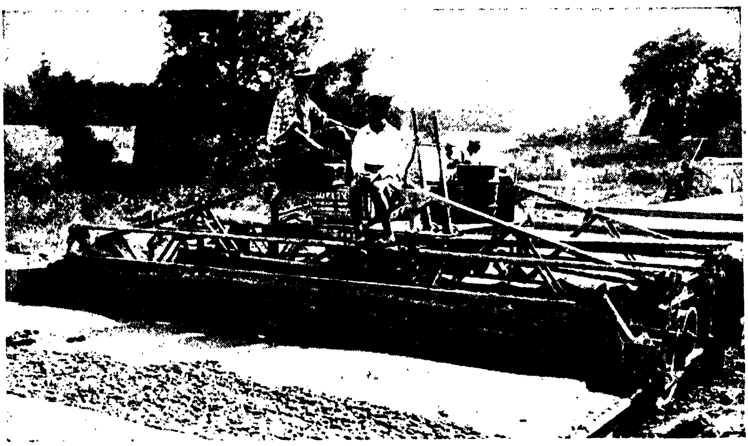


FIG. 9-4.—A finishing machine making the second run over the surface.

section of surface are sufficient. The machine is followed by the longitudinal float and the other operations which follow hand shaping and compacting.

Finishing machines are almost universally used where the width and crown are constant. They cannot be used where the crown is variable. Nor can they be used where the width is variable except sometimes on widening work when it may be possible to place a flangeless wheel on one end and permit the screeds to overlap the old pavement. They were little used on city streets until the adoption of the present low crowns, which they helped bring about. With low crowns a middle portion of pavement may be laid with the machine continuously through intersections since the low crown is not objectionable to cross traffic. Side strips reaching to the gutter are then laid by hand and warped as may be necessary.

Finishing.—The finishing operations are belting, edging, and brooming, which are always done by hand.

Belting was devised by H. B. Bushnell,[1] the idea being suggested by the use of a strip of folded canvas used in an emergency to finish a small piece of work left by striking workmen. It was first used by the Illinois Hydraulic Stone and Construction Co., of Elgin, Ill., in 1916 on the road between Elgin and St. Charles.

A canvas or rubber composition belt 6 to 8 in. wide is used. It is made about 3 ft. longer than the width of slab and provided

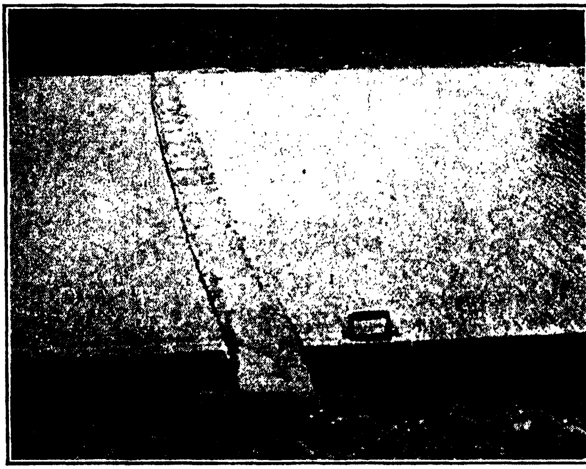


FIG. 9-5.—The finishing belt. This is a view of the original belt used for the first time in 1916.

with a cross-bar handle at each end. It is operated by two men who seesaw it back and forth across the pavement, at the same time advancing a little with each stroke. The first belting is normally given immediately following the straightedging, although a preliminary belting sometimes precedes the straightedge. It is done with rather long strokes and slow advance. The final belting is given just before the cement reaches initial set and is done carefully with short strokes and rather rapid advance, which should leave a granular surface similar to that left by a hand float. Intermediate beltings are made as desired.

The *edging* is done after the belting as soon as the concrete has stiffened enough to work properly. All of the edges of the slab such as those along the forms, at expansion joints, and at the

[1] At that time division engineer of the Illinois Highway Department.

end of a day's run are carefully smoothed with a *hand float* and rounded to a radius of about ½ in. with an *edger*.

Brooming was introduced about 1930. Its results are a surface that has less glare, a somewhat higher antiskid factor, and greater freedom from scaling. When the concrete has stiffened to the proper degree, a fiber broom, similar to the push broom used for street cleaning, is placed on the center line and pulled to the edge of the pavement. It is then moved forward its own length for the next stroke so that each part of the surface is

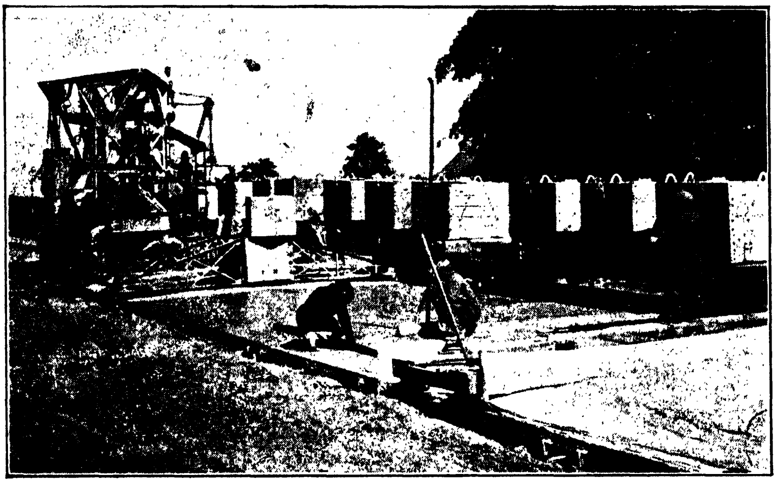


FIG. 9-6.—View showing mixer served by industrial railway, side forms, finishing machine, long-handled float, movable bridge, burlap covering, and the straight-edging of the joint with the previous day's run.

broomed but once. This process removes the silt and laitance leaving sound mortar exposed and slightly roughens the surface. Brooming is not as yet (1935) universally used but seems to be gaining in favor.

Finishing in the rain is sometimes necessary. All of the operations should be hastened as much as possible so that the burlap covering mentioned later can be placed. Parts too soft should be temporarily covered with burlap. Rain seems to cause the concrete to stiffen rapidly; consequently all unfinished portions should be watched so that they can be finished properly. With a little care a rainstorm need not result in any real damage to the pavement although the surface may appear sandy or pitted.

Protecting and Curing.—In dry weather *checking* or *hair crack-*

ing may result from the rapid evaporation of the water in the concrete before the cement has gained strength enough to resist the resulting shrinkage. To prevent this the evaporation must be reduced. The most common method is to use a covering of wet burlap. Sheets of 12-oz. or heavier burlap are saturated with water and carefully spread over the surface as soon as this can be done without marring the finish. They are kept moist for at least 24 hr. when they may give place to the regular curing procedure.

The object of *curing* is to retain enough water in the concrete to hydrate the cement properly. Many methods are therefore

FIG. 9-7.—Earth covering.

FIG. 9-8.—Ponding.

available. *Ponding* consists of building earth dikes dividing the surface into pools in which water is kept to a depth sufficient to cover the surface. *Sprinkling* from pipes fitted with sprinkler nozzles or by hand with hose is an excellent method but requires considerable water. A *covering* of *earth, sand, hay, straw,* etc., kept moist by sprinkling may be used. This saves water and keeps the surface more uniformly moist. Straw is one of the best of these covers since it holds moisture well and also acts as a lagging, tending to hold the heat in, which aids in curing. This is especially valuable in cold weather. *Calcium chloride* applied to the surface at the rate of 1½ to 2½ lb. per square yard will deliquesce in suitable climates and form a water film on the surface. Unfortunately there seem to be some deleterious effects at times so there is some controversy as to the real merits of this method. Nevertheless, many miles of roadway have been cured with calcium with apparent success. Its utility is doubtful in arid regions, and in areas of heavy rainfall it is likely to be washed away and its value lost.

Other methods of curing consist of spraying the surface with a suitable bituminous material to prevent evaporation, the use of

sodium silicate, and the use of heavy impervious paper, saturated building felt, etc. All of these will give good results when properly handled so that the real problem is to select the one that will be effective and at the same time the lowest in cost under the given conditions.

The *length of curing period* depends on the curing conditions and methods, and on the strength required at the time traffic is admitted to the roadway. Formerly an arbitrary period ranging from 10 to 30 days was specified and often rigidly enforced despite the fact that concrete hardens faster in hot weather than in cold weather. At present it is becoming common practice to base the curing time on tests of the concrete as outlined in Chap. 4 and open the pavement to traffic when a safe strength has been attained. Automobiles only may be admitted to the pavement when a modulus of rupture of about 400 lb. per square inch is attained and all traffic when this modulus reaches 700.

Checking the Surface.—The surface is usually checked for accuracy after it has hardened. The contractor may be penalized for variations greater than those permitted by the specifications. This checking may be done when the burlap protection is removed but often is done later. A 10-ft. straightedge of the ordinary type may be used or the traveling straightedge may be employed. This little machine consists of an arrangement of hinged beams mounted on wheels and provided with pointers in such a way that when it is rolled along the surface a signal is given whenever a variation greater than that specified is encountered. The surface is usually checked approximately on the lines where the wheels normally run.

The pavement may also be checked for thickness. Careful preparation of the subgrade and proper shaping and finishing should give correct thickness. This may be tested by taking levels on cross-sectional lines at suitable intervals on the subgrade just before the concrete is placed, and then again on the same lines when the concrete has hardened. The difference in the reading will give the thickness. Frequently cores about 4 in. in diameter are drilled from the pavement at chosen intervals. These give positive evidence of the thickness, and then these cores can be sent to the laboratory and tested to determine the actual quality of the concrete (see Fig. 9-9).

Shaping Intersections.—The proper shaping of intersections to secure good appearance, good drainage, and good riding

qualities requires judgment, skill, and a good eye. Machine striking cannot, in general, be used since the surface must be warped. Where one or both of the pavements is at least 36 ft. wide, the middle 18 or 20 ft. may be formed with the machine, the grade being carried through on the more important street. The crown on the minor street is flattened out against the edge of this center strip and the side portions shaped by hand. This complicates the shaping somewhat but the general scheme outlined below can be modified as desired.

FIG. 9–9.—Core drill for taking pavement specimens.

The crowns of the two streets cannot be carried straight into the intersection, for this would form a surface like a groined arch and would be rough riding. The best method is so to shape the surface that the crown on the diagonals has the same shape as the transverse crown of the adjacent portions of the street, and the transition from one to the other is made gradually. With flat crowns it is desirable to increase the crown on the diagonals somewhat in order to avoid a flat place in the center of the intersection. The amount of such increase should not exceed about $\frac{1}{4}$ in. for each 12 to 15 ft. of width, when the average width of the two pavements is used.

To assist in shaping the intersection, stakes should be set to grade at convenient points. The most important points are the center and the expansion-joint corners shown at *A*, *B*, *C*, *D*, *E* in

Fig. 9-10. With curbs (or forms) in place the elevations at B, C, D, E are known or found from level readings. The elevation of A may be found from the center-line grades or may be taken as the average of B, C, D, E plus the increased crown c. Figure 9-11 shows the diagonal DB with the slope $2h$ equal to the difference in elevations (or rod readings) at D and B. The tangent to the crown at A is parallel to DB; hence $m:h::Ab:AB$ and can be determined since the dimensions are known. With parabolic or circular crown the offset n varies with the square of the distance from A; hence $n:c::\overline{Ab}^2:\overline{AB}^2$. The elevation of b can now be found from that of A. The elevation of any other point f is found in the same way. The same process is used on the other half of the diagonal, except that m and n will have opposite signs since the tangent slopes up from A, while the offset remains below the tangent.

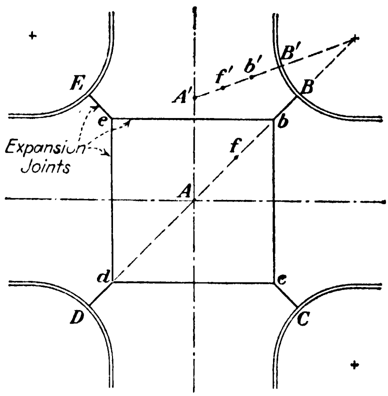


FIG. 9-10.—Locating grade stakes in an intersection.

If points other than those on a diagonal are desired, choose a point A' on a center line and determine its elevation from A and the given grade. Make the line $A'B'$ radial to the corner curve and determine the elevation of B'. The elevation of the points b' and f' can be found by the same method as on the diagonal, since h will equal the difference in elevation of A' and B' minus

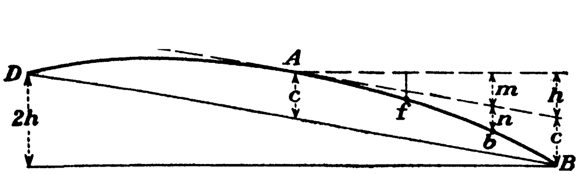


FIG. 9-11.—Diagram showing the relative elevations of the pavement surface on the diagonal of a tilted intersection.

the crown. The same process is used in any quadrant, care being taken to give the proper algebraic signs to m and n.

Skewed intersections are figured in the same way. Radii of the corner curves extended to the center lines are used at the

curves, while the direct crown is used where the curb is parallel to the center line.

The crown at the expansion joints, such as *eb* in Fig. 9-10, may be wanted, generally for the purpose of making a header board to use in placing the joint. For all practical purposes this crown may be taken as the ordinate *n* for the point *b*.

In complicated intersections it is convenient to set the stakes as outlined above and then stretch strings in various directions between them. Then, by getting down flat on the ground and sighting along the strings, irregularities can be corrected and additional stakes placed as desired.

FIG. 9-12.—Surface scaling.

The stakes used for this purpose should be such as will definitely show the elevation of the concrete and which can be readily pulled after the concrete is spread. After the stakes are set, the subgrade should be checked and corrected as may be needed to give correct thickness of concrete. The concrete is spread by the puddlers to the depth shown by the stakes and worked to shape by the finishers with long-handled floats, aided sometimes by the longitudinal float and straightedge. This work can be greatly facilitated if some one with a good eye for such things will get down low at various places around the intersection and indicate low spots and humps to the finishers. It is hard to see them when standing and handling the float.

Scaling.—Considerable difficulty has been experienced at times with the scaling of the surface. This usually occurs during or after the first winter and may continue for some time. A layer from ¼ to ½ in. thick scales off in irregular patches, exposing the coarse aggregate. In time the scaling may remove a layer from the entire surface. Usually only a single layer scales off but in a few cases two or more layers have scaled. This scaling results in very bad appearance and makes the pavement

somewhat rough to traffic but generally does not appear to seriously affect the wearing qualities.

Scaling seems to be due to the concentration of the laitance, silt, etc., in the cement and the aggregate into the top layer of the slab. The immediate causes of this condition apparently are too wet a mix, too much tamping, too much working the surface with roller and belt, and working on the surface after the cement begins to set. It is thought that unsound aggregate also contributes to or causes scaling. There is no cure for the scaling when it once starts. It can be prevented by using clean aggregates, proper consistency, and good workmanship in tamping and finishing. Brooming seems to have helped to reduce scaling.

Expansion and Contraction.—Concrete expands and contracts with changes in temperature. With a rise in temperature the concrete expands and, unless the ends are free to move and there is no friction with the subgrade, internal compressive stresses are developed. A fall in temperature produces tensile stresses.

The amount of such stress is

$$S = ctE \tag{9-1}$$

where S is the unit stress, c the coefficient of expansion, t the temperature change from the condition of no stress, and E the coefficient of elasticity of concrete.

If the ends are restrained, this stress is developed immediately, but if the ends are free it occurs only when there is a sufficient length of pavement involved to produce an equal force by friction with the subgrade. The length required to do this is

$$L = \frac{S}{fW} \tag{9-2}$$

where L is the length in feet, S the stress in pounds per square inch, f the coefficient of friction with the subgrade, and W is the weight in pounds of a prism 1 in. square and 1 ft. long. If S is the ultimate strength, L is the length required to cause failure.

In English units c may be taken as 0.000006 per degree Fahrenheit, E as 3,000,000, W as 1, with concrete considered to weigh 144 lb. per cubic foot,[1] while f varies between 0.7 and 2.0, usually being taken as about 1.0 to 1.2.

[1] This figure is used because it is sufficiently accurate and is convenient in computations since a prism 1 in. square and 1 ft. long weighs 1 lb.

Concrete also expands and contracts with changes in moisture content. The laws governing this change of volume are not well established. Furthermore, the amount of the expansion is generally less than that due to temperature and therefore consideration of expansion due to moisture is omitted.

Blowups.—In the foregoing analysis the pavement was assumed to be restrained in such a way as to act only in direct compression with a rise in temperature. It is restrained laterally by the shoulders and by the stiffness of the slab due to its width. From below it is restrained by the subgrade and the stiffness due to its thickness. From above the only restraint is the stiffness due to thickness and the weight. If a vertical upward component of the expansion develops in excess of the vertical resistance of weight and beam action, a *blowup* occurs.

Anything which causes an unbalancing of the compressive forces may result in a blowup. Abrupt changes of grade, and expansion joints not perpendicular to the surface of the slab, have been fruitful sources of blowups. A sharp settlement of the subgrade may result in blowups adjacent to it. The warping of the slab, discussed later, also contributes to blowups.

Contraction Cracks.—Reduction of temperature may cause contraction cracks. Since the tensile strength of concrete is much less than its compressive strength, it does not require so much change of temperature or so great a contributing length to cause contraction cracks as it does to cause a blowup. The most dangerous period for such cracks is when the concrete is green and of low strength. A marked reduction in temperature in the first few days after laying the pavement may result in frequent cracks. Equation 9-2 shows that, with $f = 1$, the length in feet required to develop resistance enough to cause rupture is equal to the ultimate tensile strength in pounds per square inch. Thus well-cured concrete might form cracks due to simple contraction at intervals of 600 to 1,000 ft., while in fresh concrete they might occur at much less than 100 ft.

Warping.—Difference in temperature between the top and bottom of the slab results in change of shape termed *warping* or *curling,* which unquestionably plays an important part in the behavior of concrete slabs.

Warping is *spherical* in form and hence affects the pavement in all directions. The familiar *rumbling* of grout-filled brick pavements and sometimes of concrete slabs is doubtless due to the

doming up of the pavement when the surface is warmer than the subgrade. With a reversal of relative temperatures the edges may lift, causing the pavement to rumble at the sides and expansion joints.

Warping causes stresses in the slab due to weight of the unsupported portion of the pavement and any loads which may come upon that portion. These stresses are hard to estimate owing to the indefiniteness of the manner and extent of subgrade support to the warped slab. Investigations indicate, however, that the maximum moment may occur 6 to 8 ft. from a free edge, and that the stress due to weight alone may reach 100 lb. per square inch.

If the temperature is assumed to vary uniformly from top to bottom, the resulting radius of curvature of the slab in any vertical plane is

$$R = \frac{d}{ct} \qquad (9\text{-}3)$$

where R is the radius in feet, d the thickness of the slab in feet, c the coefficient of expansion, and t the difference in temperature between top and bottom.

The departure of a circle from a tangent is given with sufficient accuracy by the equation

$$Y = \frac{b^2}{2R} \qquad (9\text{-}4)$$

where Y is the desired tangent offset, b is the distance from the center line to the edge or corner of the slab, and R is the radius from Eq. 9-3, all in feet.

Transverse Warping.—The transverse effect of warping is to change the longitudinal support of the slab. When the top is the warmer the center rises, throwing the support toward the edges. With the top the cooler, the edges are unsupported and the weight is carried along the middle portion. Under both of these conditions of support, live and dead loads tend to cause failure along the center line.

If an 18-ft. slab 6 in. thick and a differential temperature of 20°F. (which is not unusual) is assumed, the theoretical warping amounts to nearly ⅛ in. With a 28-ft. city street slab 7 in. thick, the warping is nearly ¼ in. The actual warping is less than the theoretical by the amount of deformation caused by the weight of the unsupported portion.

By using a center joint, thus cutting the width in two, the deformation is one-fourth as great and therefore the slab will lie in closer contact with the subgrade and get better support.

It is frequently stated that warping raises the center in the daytime and the edges at night. This occurs only on normal days with the normal diurnal change of temperature. It must be remembered that the center rises when the air is warmer than the subgrade, and the edges rise when the subgrade is warmer than the air. These relative conditions may occur at any time depending on the weather conditions but such reversals are especially frequent in spring and fall.

Diagonal Warping.—This serves to elevate or depress the corners of the slab. Measurements on the Bates road showed distinctly that at times the corners were lifted entirely free from subgrade, thus becoming unsupported cantilevers. It was also observed that corner breaks were the most common. These facts were the basis of Older's method of designing slab thickness.

Longitudinal Warping.—The longitudinal effect of warping has received little attention. Warping undoubtedly plays an important part in the formation of transverse cracks in exactly the same manner as in the formation of longitudinal cracks.

In a slab of indefinite length, an increase in surface temperature would cause it to bow upward. This, however, could not endure since the weight of the slab alone would be sufficient to break it down. Such action would be progressive in a manner depending on the temperature change, the character of the subgrade support, and the restraining influence of the broken sections on each other. These conditions are extremely complicated, if not impossible of analysis. By assuming certain conditions of support and mutual restraint, however, it can be shown that transverse cracks may occur 25 to 50 ft. apart as a result of the tendency to warp longitudinally. The ultimate result of the combined action of direct expansion and contraction, warping, and subgrade variation is a series of transverse cracks which break the pavement into a succession of relatively short slabs. Each of these warps *spherically*, causing the corners and edges to rise and fall, relative to the center, as has already been outlined. The ends also tend to rise and fall but the movement may be modified by the restraint caused by abutting sections, dowel bars, loads, etc.

In all probability, measurements would show that the longitudinal profile is constantly changing with the temperature. Contractors often claim that the pavements change shape after laying. Others assert that concrete pavements seem rougher on a hot day and the author has been inclined to the same opinion. The same might be true during a cold wave. These phenomena are by no means improbable but as yet have not been measured. They can be attributed almost entirely to warping.

Lateral Bending.—From the very nature of things a concrete road must constantly tend to bend or twist laterally. Deep

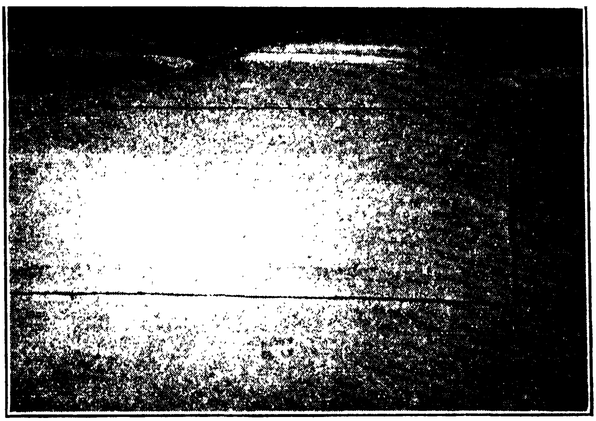


FIG. 9-13.—Expansion joints at an intersection.

cuts, trees, buildings, etc., which shade part of roadway or protect it from the winds, and perhaps other causes must result in unequal temperatures between the edges or different parts of the slab. These differential temperatures certainly will set up lateral bending in addition to other forms of warping. It is quite probable that herein lies the answer to many questions as yet unsettled, such as the unequal opening of transverse joints and cracks, the irregular opening of center joints, a center crack diverging to edge of slab for no apparent cause, and other similar phenomena.

Transverse Expansion Joints.—In order to relieve the longitudinal expansion and contraction and help to control transverse cracking, transverse expansion joints are often used.

On rural highways, a shifting of the position of slab is unimportant except near bridges, etc. A movement of several inches

may often be unobservable. Therefore, transverse joints may be spaced at long intervals or often omitted entirely.

On city streets, such movement cannot be permitted. Street intersections, inlets, manhole covers, driveways, etc., all form "anchor points" where very little movement can be tolerated on account of resulting damage. Each section of the pavement must therefore remain practically at the exact place it is laid. For these reasons city streets require expansion joints.

The joints should be placed close enough together to be effective and yet no oftener than necessary on account of the cost of installation and maintenance, and the difficulty of getting them smooth. Experience seems to indicate that a spacing of 30 to 40 ft. gives the best results. The spacing can be modified by the kind and amount of steel reinforcement.

The width of the joint itself is a function of the spacing and of the ability of the joint material to take compression. Most joint materials should not be compressed more than about 20 percent; hence the width of joint should be about five times the expansion per slab. For a 30-ft. slab and 50°F. change in temperature, this results in a width of joint of a little over $\frac{3}{8}$ in. Experience shows that joints about $\frac{1}{2}$ in. wide are the most satisfactory for this spacing. The temperature range to be used in determining the width of joint should be that between the temperature at which the pavement is laid and the maximum summer temperature. Thus pavement laid in cold weather should have wider joints than those laid in hot weather. This distinction, however, is rarely made in practice.

High temperatures will cause bituminous joint material partially to squeeze out. On cooling, it does not reenter the joint and is ultimately lost. The joints, therefore, need occasional refilling with bituminous cement.

A reduction of temperature causes the joints to open. If possible, the filler should adhere to the edges of the slab and spread to keep the joint sealed. If it does not, dirt and water enter, possibly causing expansion troubles or at least ultimate deterioration of the joint filler. This is an additional reason why the joints should be kept filled.

Where the curb, or curb-and-gutter, is doweled to the slab, the expansion joints must be continuous through both the slab and the curb. The latter is usually placed first; hence the joints are located therein and must be properly spaced. The joints in the

slab must then meet them exactly or cracks will result, usually in the curbs but sometimes in the slab.

Installing Expansion Joints.—There are three types of expansion joints, the poured bituminous joint, the premolded asphalt joint, and the metallic joint.

The poured joint is made by means of a tapered board or its equivalent set in the pavement when the concrete is placed. When the concrete is hard, this form board is removed and the space poured full of a suitable filler. This type is now little used for ordinary joints but may be employed for special joints especially those 2 in. or more in width.

The premolded asphalt joint (see Chap. 3) is perhaps the best type. Since it is imperative that the joint extend through the slab, it was formerly the custom to use material wider than the depth of slab and permit it to extend above the slab during construction, later cutting it off. Present practice is to keep the filler about ½ in. below the surface. This is a little harder to do but gives a smoother joint and also permits the use of a finishing machine.

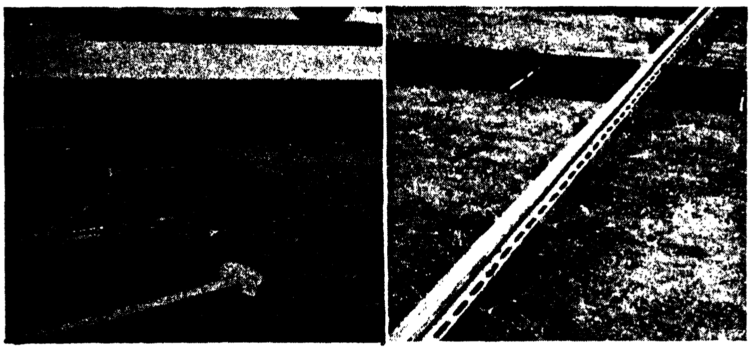
At intersections the arrangement of expansion joints and the construction program should be such that all joints can be finished from a bridge, the ground, or hardened concrete. The workmen should never be permitted to wade into the concrete to finish a joint. In a rectangular intersection the main pavement may be laid continuously and the turnout wings omitted until later, or the wings may be laid first and the main pavement then laid between them. In skewed and other complicated intersections a definite joint layout avoiding acute angles should be made in advance. A construction program should then be prepared showing the exact order in which the sections are to be laid so that the joints can be properly reached. This often requires considerable study and skill and therefore should never be neglected.

Similarly, the filler should extend entirely to the bottom of the slab. Rarely is a subgrade true enough so that simply setting the filler on the ground will not leave spaces the concrete can flow under. This can be easily overcome by notching the joint into the subgrade.[1] A small groove is scratched into the subgrade with a narrow mattock or pick, the filler set in the groove, and

[1] This scheme was proposed by the author in 1914. Experience indicates that it is well worth the effort and it is standard practice in many places.

the earth tamped against it. This is easily and quickly done by the regular joint men with no objectionable increase in their labor and, therefore, its additional cost is practically zero. In this way the concrete is sealed from passing under the joint and at the same time the filler receives support at the bottom which aids in keeping it in place while the concrete is being deposited. This latter feature is much liked by the laborers as well as the contractor and engineer.

The filler must not have gaps in it—a point often neglected. It is better to lap two sheets than not have them meet. The



A *B*

FIG. 914.—*A*, premolded asphalt joint notched into the subgrade; *B*, the *ACE* metallic joint. Note the dowel bars in *A* and the *J*-bars in *B*.

expansion-joint manufacturers supply barbed clips to fasten the sheets together and these should always be used.

Various devices are employed for supporting the filler while the concrete is placed. The most common is a wooden board or bulkhead staked to place and the filler set against it. The concrete is placed on both sides and then the plank carefully pulled, the concrete being tamped under it to prevent the filler being displaced. A metal holder is sometimes used in place of this plank. The principal difficulty with either of these devices is a tendency to pull the filler up with them. This could be materially overcome if the boards were kept clean and free from hardening concrete. Several special devices to hold the filler down are on the market.

A number of so-called metallic joints having copper seals to exclude dirt have been placed on the market. One of the best known of these is the *ACE* joint shown in Fig. 9-14. Such joints are assembled in complete units which are set in place and staked

with metallic stakes. Since they are of fixed dimensions the subgrade must be accurately formed where the joint is placed. These joints are expensive and so far have not been very successful, principally because of comparatively early failure of the copper seals.

Transverse Contraction Joints.—Attempts have been made to control transverse cracks caused by contraction by inserting *contraction joints* between the expansion joints. These are merely artificial cracks generally made by means of a metal plate, a sheet of heavy paper against a header board, or as the result of the end of a run. Such joints tend to open in cold weather, which permits the entry of water and dirt which may hold the joint open so that the next expansion tends to close the adjacent expansion joints by the same amount, thus tending permanently to open the contraction joint and close the expansion joint. It would, therefore, seem better to increase the number of expansion joints, making them correspondingly narrower, and omit the so-called contraction joints. The *ACE* metal joint has a crimped copper strip intended to seal the joint and prevent this trouble.

Doweling Transverse Joints.—In order to prevent the joints from becoming uneven as well as to transfer part of the load from slab to slab, it is now general practice to insert dowels across all transverse joints. Such dowels are especially advantageous at street intersections where the middle slab is entirely surrounded by expansion joints and, therefore, entirely free from the adjacent slabs.

Such dowels must be heavy enough to act without sensible bending. They must be spaced close enough to carry the loads across and must be so installed as not to interfere with normal operation of the expansion joint. With ½-in. joints, ¾-in. bars are probably the smallest size to use with a spacing of about 3 ft. These dimensions cannot be exactly computed on account of certain indefinite factors such as the lateral distance the slab will transfer a load and the looseness of the bar.

In order that the slab may expand, the bond with the dowels must be broken. Painting and then greasing is effective. In addition, *end space* for the sliding of the bar in and out must be provided. This calls for some method of providing an open space in the slab the size of the bar and long enough to take up the movement of one or both ends of the bar. The most common device is a light sheet-metal tube crimped shut at one end and

slipped on to the end of a bar so as form a cap with an open space at the end of the bar. Similar tubes of cartridge paper have been used.

Longitudinal Expansion Joints.—Longitudinal expansion joints should be placed between the slab and plain curbs, between all curbs and sidewalks, between walks and buildings, and at any other places where the pavement is confined laterally.

Rarely are longitudinal expansion joints placed in the pavement itself unless it is unusually wide. Generally, joints along the edge are made wide enough to make one in the body of the pavement unnecessary, thus keeping the joints away from wear by traffic.

Longitudinal joints are made of the same material as transverse joints. The width is usually ½ to ¾ in. along curbs, with an equal amount between curbs and walks and sometimes an equal amount at the building. Thus the total joint width is from 2 to 6 in. in the entire width of street. It is well to provide an excess in order to prevent excessive bleeding of the joints and to be sure to prevent stresses which might break the curb. On country roads, longitudinal joints are rare. In case the slab is confined by buildings, structures, or rock cuts, such joints should be used.

In general, longitudinal joints have new concrete placed against one side only and therefore they are simply supported in place against the curb or wall until the concrete is deposited. The necessity for having the joints extend entirely through the slab without gaps or breaks is the same as for transverse joints.

Center Joints.[1]—Center joints were suggested about 1912; but the idea received little attention until the Bates road[2] tests showed their advantage. They have now become standard practice on both rural roads and city streets. Their object is to separate the slab into narrower strips in order to reduce warping and obtain closer contact with the subgrade and thus reduce the formation of longitudinal cracks.

Center joints are made in one of four ways: (1) A deformed steel plate, forming also a tongue and groove, is staked along the center line and buried in the concrete forming the so-called *concealed joint.* (2) A joint is formed with a thin strip of pre-

[1] Proposed by S. N. Morse of Carlinville, Ill., about 1912. See *Eng. and Contracting*, July 9, 1913.

[2] *Proc. A.S.C.E.*, Vol. 50, No. 2, p. 175, February, 1924.

molded expansion-joint filler in the same way as a transverse expansion joint. (3) A plane of weakness is formed by making a deep groove along the center line by means of a wood or metal strip set in place and removed after the concrete has hardened. This is often termed a *dummy joint.* (4) A *construction joint* is formed by building the two sections of the slab at different times.

Center Joint Tie Bars.—In order to maintain the two parts of the slab at the same elevation and to transfer part of the load across the joint, it is common practice to dovetail the two parts together. To make the dovetail effective, the joint must be prevented from opening by means of adequate tie bars across the joint. The original bars as installed in slabs 18 to 20 ft. wide and 6 to 8 in. thick on the Bates test road were ½ in. in diameter and 5 ft. apart. This size and spacing have been blindly followed without consideration of differences in the width and thickness of the slab or changes in the nature of the subgrade. Such tie bars should be designed to suit the particular width and thickness of concrete and kind of subgrade.

When expansion occurs, the center of gravity of each half slab is moved outward. Subsequent contraction is toward the center of gravity of each half, thus opening the joint. Dirt, etc., getting into the joint will prevent its closing, with the result that the next expansion again moves the slabs apart. Water freezing in the joint may aid in spreading the slabs apart. Thus the joint grows until the dirt in it is sufficient to take up the expansion. The width may become several inches.

It is evident that the force to prevent spreading is equal to that required to slide the half slab over the subgrade. By knowing the length, width, and thickness of the slab and the coefficient of friction with the subgrade, the total force to be resisted can be computed. By knowing this force and the permissible stress in the steel, the size of bar for a given spacing or the spacing for a given size of bar can be determined. The length of bar is such as will give the required bond. Various tests have given value of f between 0.5 and 2.0. Values of 1.0 to 1.5 are often used for clay or loam subgrades but compacted gravel, etc., may require higher values.

Transverse cracks rarely extend directly across the center joint but generally offset a foot or more. In this way a crack may be a foot or less from one bar and 4 ft. or more from the next one. A slight lateral bending of the pavement caused by

differential temperature, as mentioned previously, or by other conditions will open the joint slightly and with the present type of joint plate render the dovetail ineffective. Corner breaks along the center line are then likely to occur. Better results would be obtained by using smaller bars spaced closer together. The maximum spacing should probably not exceed 2½ ft.

Example.—Assume a slab 20 ft. wide, 7 in. thick, $f = 1.2$, tensile stress in steel at 20,000 lb. per square inch, and a bond stress of 110 lb. per square inch of superficial area of bar. With bars spaced 5 ft., the force to be resisted by one bar is $10 \times 7 \times 60 \times 1.2 = 5{,}040$ lb. The area of steel required is $5{,}040 \div 20{,}000 = 0.25$ sq. in., which is furnished by a ½-in. square bar. The length of bar would be $(2 \times 5{,}040) \div (2 \times 110) = 46$ in.; whence a 4-ft. bar would be used. If the spacing were reduced to 2.5 ft., the area of steel per bar would be one-half as much; hence ⅜-in. square bars could be used. The length would be 2½ ft. Two ⅜-in. square bars 2½ ft. long weigh less than one ½-in. square bar 4 ft. long; hence the smaller bars closer together save steel in addition to placing it to better advantage.

Center-joint Plate.—A deformed steel plate is most frequently used to form the center joint including the tongue and groove or dovetail. These plates are made about ½ in. narrower than the thickness of slab so as to remain below the surface out of the way of the finishing work. They are staked to place with U-shaped pressed-steel pegs about 16 in. long which pass through holes in the deformed portion. The tie bars are placed through holes punched for the purpose and are kept level by pressed-steel *bar supports* driven into the subgrade, one at each end of the bar. A crack forms later above the plate and must be protected from traffic. A band of tar or asphalt about 4 in. wide covered with sand serves the purpose and at the same time forms an excellent traffic line. Other types of center joints may be protected in the same way.

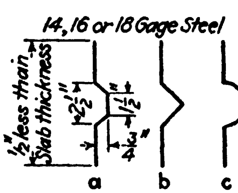


FIG. 9-15.—Types of concealed center-joint plates.

Figure 9-15 shows three styles of center-joint plates. The one to the right is least used but it is the best because there is no vertical component of the weight tending to open the joint, and a slight opening of the joint does not render the dovetailing ineffective. The middle style is the poorest as should be obvious. The one to left could be improved by making the taper of the dovetail as small as possible. All that is needed is

enough to give clearance to the dies or rolls used in forming the plate.

Multiple Center Joints.—On wide pavements more than one center joint should be used, so located as to act as traffic lines. To be effective in controlling warping and cracks, such joints should be not more than about 12 ft. apart; but this width is not always suitable for traffic lanes since a running lane should be 9 to 12 ft. wide and a parking lane 7 to 9 ft. (See Chap. 16.)

On rural roads only running lanes are paved. A two-lane road is built with a regular center joint. A three-lane road may be built in three strips with construction joints between or a double lane may be built with a center joint and widened with a single-lane slab which may or may not be tied to the other. On four-lane roads two double-lane roads are usually built. They may or may not be tied together. If ties are used, each joint should be analyzed to determine the size and spacing of the tie bars. Similarly, the spaces between joints should be analyzed for mesh reinforcement as explained later.

City pavements under 30 ft. wide back to back of curbs are usually laid with only one center joint, especially if a curb-and-gutter is used which reduces the width of slab subject to warping to 13 ft. or less. Pavements 32 to 40 ft. wide should be considered as having two running lanes down the middle; hence a 20- to 26-ft. two-lane slab having a regular center joint can be laid in this portion and the side strips added. Wider pavements should be arranged in lanes as seems necessary for parked and running traffic.

On city streets all longitudinal joints should be tied together. Each joint should be analyzed for size and spacing of bars, with the contributing width the distance from the joint to the nearest edge of pavement, including the curb-and-gutter if it is tied to the slab. In addition, the spaces between joints should be investigated as outlined under mesh reinforcement.

Construction joints are made by setting regular forms for the first strip of slab. After the forms are removed, the first strip serves as the form for the second. Dovetails can be provided by fastening sections of center-joint plate or a wooden strip to the forms. Holes should be made in the forms, whether of wood or steel, for the tie bars. These should be kept essentially straight. The practice of bending the bars 90 deg. and setting them in the concrete with one leg against the forms to be later dug out

and bent outward is decidedly crude and unsatisfactory. It is bad enough for shear dowels and should not be tolerated for ties. There are no objections whatsoever to placing holes in the forms. In fact, the form manufacturers would do well to punch holes in the forms every $2\frac{1}{2}$ ft. (four to a 10-ft. section of form). This would be of some assistance in the design of the bars and most certainly would help the contractor to place them properly.

Mesh Reinforcement.—On two-lane roads experience and computation show that the concrete is strong enough to take the stress due to lateral expansion beyond the ends of the center-joint tie bars. On wide pavement this is not true for the interior joints, and critical sections exist at the ends of each set of the bars. These sections should be analyzed for required steel the same as was the center joint. Generally, however, reinforcement of steel wire mesh is used instead of bars for reasons stated shortly.

If transverse joints are installed, a critical section exists midway between adjacent joints. This section should also be investigated for the amount of steel the same as the center joints. This reinforcement runs longitudinally; hence when it is combined with the transverse reinforcement already figured the most convenient method of placing the reinforcement is in the form of mesh. Tests by the U.S. Bureau of Public Roads indicate that small bars spaced closer together are more effective than larger bars spaced farther apart. Mesh fabric of steel wire with the wires spaced not more than 12 in. apart, and generally 6 in. apart, is, therefore, the usual form of such reinforcement. The strength of the concrete is neglected in computing the mesh, since cracks may form from several causes, and the mesh must hold the slab together in every case.

Mesh reinforcement is made in several styles, but the one generally used has wires crossing each other at 90 deg. and spot welded together. Tables 2-8 and 2-9 give the dimensions of the more common forms of mesh used, but almost any combination of size and spacing of wires can be had. The mesh is usually cut into sheets to fit the sections of slab and shipped flat, which greatly facilitates its handling. The sections of mesh should be well lapped. Since the cross wires give mechanical bond, it is sufficient to lap them one mesh, or distance between adjacent wires, and the size of sheets should be such as will permit this. Since mesh is made of drawn wires, a higher stress can be permitted than is used for bars.

Example.—Assume a pavement 40 ft. wide, 7 in. thick, divided into four strips 10 ft. wide by three longitudinal joints, transverse joints spaced 30 ft., and $f = 1.2$. From the previous example (page 230) the side joints would require $\frac{3}{8}$-in. square bars $2\frac{1}{2}$ ft. long, spaced $2\frac{1}{2}$ ft. The center joint would require twice as much steel, which would be sufficiently satisfied by $\frac{1}{2}$-in. square bars 4 ft. long spaced the same. The critical section lies at the end of the center-joint bars; hence the force per foot of slab is $18 \times 7 \times 12 \times 1.2 = 1{,}815$ lb. The area of steel wire per foot would be $1{,}815 \div 22{,}000 = 0.082$ sq. in. Table 2-8 shows that No. 4 wires spaced 6 in. is the nearest and hence would be used. With transverse expansion joints spaced 30 ft., the critical section would be midway between them; from this it would be found that longitudinal wires having an area of 0.075 sq. in. per foot width of slab would be needed. This is almost the same as the transverse wires; hence a square mesh composed of No. 4 wires spaced 6 in. would be used. Between the side joint and the edge of slab no transverse wires would be required, as already stated; but the longitudinal requirement is the same as just found. A mesh having No. 4 longitudinal wires spaced 6 in. but with transverse wires only sufficient to hold the mesh together, say No. 10 at 12 in., would be sufficient.

Bar Reinforcement.—Bar reinforcement may be light weight to serve the same as mesh or may be designed to take bending stresses. Since the condition of the load and support of a slab cannot be accurately estimated, the design for bending is far from exact and is largely empirical. Bar reinforcement is usually made into *mats* or units and set in place, providing reinforcement at both top and bottom of slab.

There is no question but that such reinforcing can be made to increase the load capacity of the slab but its cost becomes high if not prohibitive. Its economic value is therefore not as yet established.

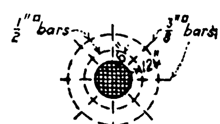


FIG. 9-16.—Reinforcing at manhole.

Manhole Reinforcement.—Experience shows that many cracks start at manholes, etc. Reinforcement should, therefore, be provided to prevent this cracking as far as possible. It is practically impossible to arrive at an estimate of the forces; hence this reinforcing is made arbitrarily. Figure 9-16 shows a satisfactory method.

Marginal Reinforcement.—The Bates Road Test and other tests developed the idea of marginal reinforcement. Two ideas seemed to find expression as follows:

First, it was noticed that all cracks started at exposed edges of the slab. Hence marginal reinforcement by holding the

edges together would prevent these cracks. For this purpose the reinforcing should extend entirely around the edges of the slab. Its size can only be guessed at but full bond is desired. This method is applicable only to pavement with transverse expansion joints. Where such joints are not provided, trouble will always develop owing to the concentration of expansion stresses by the bars.

Second, a marginal bar was presumed to act as a continuous dowel. Part of the load is carried across the crack by simple shear, thus reducing the stresses which tend to cause corner failures. In this case, bond may become highly objectionable, as under some condition of slab expansion and movement it is likely to cause concentration of expansion stresses. To prevent bond, the bars are painted and oiled. Wherever trouble with the marginal bar has occurred, it is almost invariably due to the development of bond by careless oiling or by kinks in the bars.

The bars are installed by using any of several special bar supports on the market.

Corner Reinforcement.—Corners often exist where it is impossible or impracticable to use dowels or to thicken the slab, as, for example, at street intersections or railroad crossings. Such corners should be reinforced against downward bending. The amount of steel cannot be readily computed because the variable cross-section of the slab and the indefinite character of the subgrade support make it impossible to establish the position of the plane of maximum stress, or probable fracture.

It is possible, however, to approximate the amount of steel by considering the corner as a free cantilever then assuming a position of the plane of rupture, after which the amount of steel can be computed in the ordinary way. Several probable sections can be investigated, as may seem advisable. The ordinary reinforced beam formula (Eq. 12-1) gives more steel than is necessary because it omits the tensile strength of the concrete. Since the cracking of a pavement slab is not immediately followed by its complete destruction, or by danger to traffic, it is permissible to use a lower factor of safety than would be advisable in a building or a bridge, which in this case may be done by allowing for the strength of the concrete. The procedure in determining the amount of steel would then be first to compute the load which the plain slab could carry and then compute the amount of steel required to carry the remainder of the actual load.

In case the slab breaks, it will deflect at the crack, until the corner rests on the subgrade, and thus relieve some of the stress in the bars. The bars will then act as dowels holding the parts together and distributing the loads so that further failure is prevented or proceeds slowly.

Figure 9-17 shows a method of reinforcing corners at intersections which is frequently used. The bars are usually ½ in. square and about 5 ft. long. The common idea is to use standard

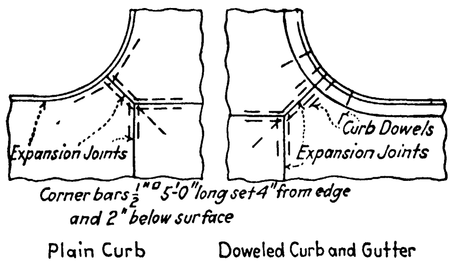


FIG. 9-17.—Corner reinforcement at street intersection.

bars used elsewhere in the work. The reinforcing is somewhat light but it has yielded excellent results with practically no failures, except under excessive loads.

Protection Plates.—Steel protection plates are desirable at all exposed ends of the slab which meet a soft pavement or unpaved roadway. They are also generally used along the edge of a slab adjacent to street railway tracks where some other form of pavement is used in the track area. There is some question whether this scheme is really advantageous, as the plates often come loose and damage tires. If the pavements are properly maintained the plate is superfluous.

The plates are soft steel, about $\frac{3}{16}$ by 2½ in., with fins about ¾ in. wide and 5 or 6 in. long, spaced about 18 in. apart, sheared loose, and bent outward to anchor the plate to the concrete. These plates are supplied straight or bent to crown and in nearly any desired length. The crown can be adjusted somewhat by peening along the edge to be lengthened to change the curvature.

The plates are installed by nailing them to wooden header boards or side forms with six-penny nails driven halfway in and bent over. These hold it sufficiently during installation and pull out easily when the board is removed. The concrete is finished to the top of the plate.

Thickness.—Several methods have been proposed for computing the thickness of a concrete road slab. The principal theories are as follows:

Older's Method.[1]—This method is based on the established facts that a corner is a critical section and that due to warping any corner may at times become an unsupported cantilever. It is then assumed that the wheel load is applied at a 90-deg. corner and that rupture occurs in a plane at right angles to the bisector of the corner, or across an imaginary beam of indefinite width.

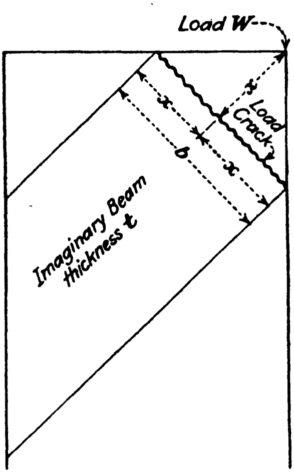


FIG. 9-18.—Diagram of conditions assumed in computing slab thickness.

From Fig. 9-18 the bending moment is Wx. From the theory of simple beams the resisting moment is SI/C. Equating, substituting values of I and c for a rectangular homogeneous beam of width $2x$, and thickness t_c, and reducing,

$$t_c = \sqrt{\frac{3W}{S}} \tag{9-5}$$

where W is the wheel load in pounds, S is the stress in pounds per square inch, and t_c is the *corner* thickness in inches, which may also be considered the edge thickness of a plain concrete slab since an open joint or crack results in free corners.

If a continuous-edge shear bar is used, it has been found that practically one-half the load is carried across a joint or crack to the adjacent slab, from which the *edge* thickness of a doweled edge slab is

$$t_e = \sqrt{\frac{1.5W}{S}} \tag{9-6}$$

At the intersection of two joints or cracks in the interior of the slab it may be considered that four corners share the load; hence the *interior* thickness is

$$t_i = \sqrt{\frac{0.75W}{S}} \tag{9-7}$$

[1] Clifford Older, former chief highway engineer of Illinois in charge of Bates road tests.

From Eqs. 9-5 and 9-7 it is seen that the ratio between interior thickness t_i and edge thickness for a plain concrete slab t_c is $\sqrt{0.75}:\sqrt{3} = 2$, or $t_c = 2t_i$. From Eqs. 9-2 and 9-3 the ratio for a doweled-edge slab is $\sqrt{0.75}:\sqrt{1.5} = \sqrt{2}$, or $t_e = 1.4t_i$.

Westergaard's[1] *Method.*—From a theoretical analysis[2] of the problem made for the U.S. Bureau of Public Roads the following equation for the stresses in a concrete road slab were derived: For a free corner (or plain edge):

$$S_c = \frac{3W}{t_c^2}\left[1 - \left(\frac{12(1-\mu^2)k}{Et_c^3}\right)^{0.15} \times (a\sqrt{2})^{0.6}\right] \qquad (9\text{-}8)$$

in which a is the distance in inches from each edge forming the corner to the center of the load, E is the coefficient of elasticity of concrete, μ is Poisson's ratio for concrete, k is the modulus of subgrade reaction in pounds per square inch per inch of deflection, and the other terms as before. E is usually taken as 3,000,000, and μ as 0.15, while k varies between 50 and 200 for ordinary subgrade soils.

For the edge of slab without joint or crack (or with edge dowel):

$$S_e = 0.529(1 + 0.54\mu)\frac{W}{t_e^2}\left[\log_{10}\left(\frac{Et_e^3}{kb^4}\right) - 0.71\right] \qquad (9\text{-}9)$$

where $b = \sqrt{1.6a^2 + t_e^2} - 0.675t_e$ when $a < 1.724t_e$ and $b = a$ when $a > 1.724t_e$.

For an interior area of the slab:

$$S_i = 0.275(1 + \mu)\frac{W}{t_i^2}\log_{10}\left(\frac{Et_i^3}{kb^4}\right) \qquad (9\text{-}10)$$

In 1933[3] after further study Professor Westergaard modified these equations by introducing a term called the coefficient of subgrade stiffness $K = kl$, where l is the radius of relative stiffness equal to $\sqrt[4]{\dfrac{Et^3}{12(1-\mu^2)k}}$ where t may be t_c, t_e, or t_i as desired. The revised equations are

For a free corner:

$$S_c = \frac{3W}{t_c^2}\left[1 - \left(\frac{12(1-\mu^2)K}{Et_c^3}\right)^{0.2} \cdot (a\sqrt{2})^{0.6}\right] \qquad (9\text{-}11)$$

[1] Professor of theoretical and applied mechanics, University of Illinois.
[2] *Public Roads*, Vol. 7, No. 2, p. 27, April, 1926.
[3] *Public Roads*, Vol. 14, No. 10, p. 185, December, 1933.

For the edge of slab (unbroken or doweled):

$$S_e = 2.117(1 + 0.54\mu)\frac{W}{t_e^2}\left[\log_{10}\left(\frac{t_e}{b}\right) + \frac{1}{3}\log_{10}\left(\frac{E}{K}\right) - 0.266\right] \quad (9\text{-}12)$$

For an interior area:

$$S_i = 1.1(1 + \mu)\frac{W}{t_i^2}\left[\log_{10}\frac{t_i}{b} + \frac{1}{3}\log_{10}\left(\frac{E}{K}\right) - 0.089\right] \quad (9\text{-}13)$$

Evidently the foregoing equations can be used for determining the thickness t_c, t_e, and t_i for a given value of S. The relation between edge and interior thickness is not so readily determined but it can be shown that t_i is practically $0.7t_e$ for a doweled-edge slab. Furthermore, it is evident that, with the load applied at the corner ($a = 0$) or with the slab not in contact with the subgrade ($k = 0$), Eqs. 9-8 and 9-11 give the same results as Eq. 9-5.

Sheets' Method.[1]—From a study of the foregoing equations and available experimental data including the effect of solid rubber or pneumatic tires and the effect of impact, the following empirical equations applicable to thickened-edge slabs were derived:

For a free corner,
With pneumatic tires:

$$S = \frac{2.4W}{d^2} \quad (9\text{-}14)$$

With solid tires:

$$S = \frac{3W}{d^2} \quad (9\text{-}15)$$

For doweled edge,
With pneumatic tires:

$$S = \frac{1.92Wc}{d^2} \quad (9\text{-}16)$$

With solid tires:

$$S = \frac{2.4Wc}{d^2} \quad (9\text{-}17)$$

$$t_i = 0.85d \quad (9\text{-}18)$$

where d is the *effective depth* of the thickened edge, defined as the average thickness on a 45-deg. diagonal located 24 in. from the

[1] SHEETS, FRANK T., "Concrete Road Design," Port. Cem. Assoc., 1934; *idem*, Rational Road Design, *Eng. News-Rec.*, Vol. 114, No. 3, pp. 83–89. Jan. 17, 1935.

corner for a slab having simple thickening (Fig. 9-19*b*) or 30 in. for the heavy-duty type (Fig. 9-19*c*),[1] and c is a factor depending on the coefficient of subgrade reaction or the term k in Westergaard's formulas.

Empirical values of c were then determined for different values of k as follows:

k	c	k	c
50	1.096	300	0.842
100	1.000	400	0.800
200	0.900	500	0.770

To use these formulas in designing a slab for given values of W and S, compute d from Eqs. 9-14 to 9-17 as desired and determine the value of t_i from Eq. 9-18. The edge thickness or shape of thickening is then worked out from this value of t_i to provide the computed value of d.

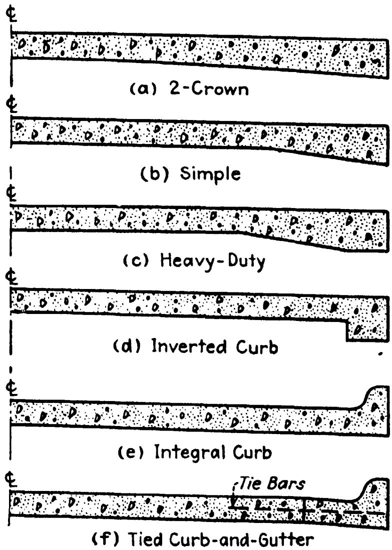


FIG. 9-19.—Types of thickened edges.

Thickened Edge.—Theoretical analysis, road tests, and service experience all show that critical sections exist wherever the wheel may run on, across, or very near any edge of a slab. It is therefore sound design and practically standard practice to make such edges thicker than the middle. Wherever the edge of a slab is supported by means of dowels or dovetails uniting it with another slab, or where curbs, etc., prevent the wheels from running close to the edge, thickening is not necessary.

Figure 9-19 shows several ways in which the thickening may be obtained. The method at *a* simplifies subgrade work but is extravagant of concrete. The schemes at *b* and *c* are most

[1] These values of d are the same as would be found on a line transverse to the center line in a length equal to the projection of the specified diagonal upon it. For the first case, d is the average thickness in a distance of 34 in. from the edge, and in a distance of 42½ in. for the second case. This simplifies finding d from a given set of drawings.

commonly used. Their principal drawback is the difficulty of forming the subgrade in some soils. The inverted curb in *d* is little used; but occasionally in special locations, such as adjacent to railroad tracks where considerable depth of edge is wanted, it is desirable. The integral curb strengthens the edge by actually increasing the thickness and at the same time preventing the wheels from getting near the edge. If a curb-and-gutter is

FIG. 9-20.—A typical thickened edge two-lane road section.

properly doweled to the slab, thickening is not required, the whole acting like any doweled joint and an integral curb.

Fatigue.—Experiments have shown that concrete is subject to fatigue the same as metals. The fatigue limits are difficult to determine; but the best data indicate that if the repeated stress is less than half the ultimate strength the stress may be repeated an indefinitely large number of times without failure. As the stress is increased above 50 percent of the ultimate, the number of repetitions rapidly decreases until only a single application of the ultimate stress causes rupture. The *working stress* should, therefore, be less than half the ultimate except for those occasional loads whose number of repetitions would be less than the fatigue limit within the probable life of the slab. Road concrete now generally exceeds a modulus of rupture of 800 lb. per square inch at 28 days; consequently a working stress of 350 lb. per

square inch should be conservative. A greater factor of safety is not necessary since no danger to life is involved in the cracking of slab, nor does such cracking immediately render the road unusable. After the first crack, additional repetitions of the load will gradually extend the failure until finally repairs or replacement may be required.

Figure 9-21 shows the relation between the stress caused by a load and the number of repetitions required to start failure.

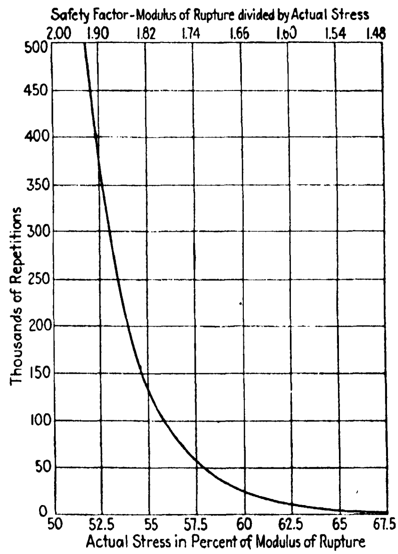


FIG. 9-21.—Fatigue curve for concrete pavements. (*Compiled from Fatigue of Concrete, Eng. Report* 34-1, *Ill. Div. of Hys.*, 1934.)

Wheel Loads.—To use any of the formulas for thickness, it is necessary to determine the load to be supported. Load limits are usually fixed by law but the actual loads may exceed these legal limits owing to willful violation of the law possibly occasioned by logical changes in the character of the traffic. In 1934 the legal weight limit as shown by Fig. 20-1 ranged from 12,000 to 24,640 lb. per axle or 6,000 to 12,320 lb. per wheel. This lack of uniformity makes sound design difficult, especially when there is a considerable amount of interstate truck traffic.

Irregularities in the road surface or small obstructions over which the wheels must pass will cause *impact* loads. The first impact tests indicated that impact loads might be several times the static load but more precise measurements now show that

the increase in stresses in the slab due to impact from such causes as are likely to occur on a highway do not exceed the static load by as much as 50 percent when solid rubber tires are used. Pneumatic tires of the medium-pressure (balloon) type greatly reduce the effects of both static and impact loads. It is generally accepted that stresses with pneumatic tires do not exceed 80 percent of those with solid rubber tires for the same loads.

For these reasons the loads used in designing road slabs should have an impact factor of 25 to 50 percent added to the static load on the wheels, such as would be found by weighing the vehicle, except with Eqs. 9-14 to 9-18 which provide for impact.

Designing for Traffic Loads.—The ordinary practice has been to design all pavements for the maximum load irrespective of the probability of such loads using the road, except for the introduction of *heavy-duty* types in metropolitan or industrial areas. Such practice probably results in unduly heavy and therefore expensive pavements in outlying areas. It would, therefore, seem that the "rational" method of design would be to combine the thickness formulas with traffic-survey data and the effects of fatigue.[1]

From the traffic survey the maximum weight of the normal traffic, omitting the occasional heavy load, is determined and a tentative design made for this normal load. The number of vehicles per year of greater weight is determined from the traffic survey and the stress due to this weight reduced to a percentage of the chosen modulus of rupture. The number of permissible repetitions is taken from a fatigue curve (Fig. 9-21). The probable life in years is then found by dividing the number of repetitions by the number of vehicles per year. If the life so found is not considered reasonable, the design is revised and the process repeated. If two or more loads of infrequent occurrence are greater than the design load, their combined effect can be found by reducing the number of loads of one weight to an equivalent number of loads of the other weight by the ratio of their respective number of repetitions given by the fatigue curve.

Example.—A tentative design for the majority of traffic is based on a working stress of less than half of the ultimate. A traffic survey shows there are 1,500 vehicles per year which would give a stress of 57 percent of

[1] Sheets, Frank T., "Concrete Road Design Simplified and Correlated with Traffic," Port. Cem. Assoc., 1934.

the ultimate. From Fig. 9-21 the number of repetitions is 66,000, from which the probable life under this load is 66,000 ÷ 1,500 = 44 years. The survey also shows that there are 700 vehicles per year which would cause a stress of 60 percent of the ultimate. This load has only 25,000 permissible repetitions, from which the life under it alone would be 25,000 ÷ 700 = 36 years. The 1,500 lighter loads are equivalent to 1,500 × 25,000 ÷ 66,000 = 630 heavier loads. The combined effect, therefore, is the same as if there were 630 + 700 = 1,330 of the heavier loads alone. The probable life under the two groups is, therefore, 25,000 ÷ 1,300 = 19 years.

The probable life as found in this manner is not the age at which the pavement is completely destroyed but merely the age at which failure from fatigue *may be expected to start.* The actual life would be much longer, depending on the rate of progressive failure and cannot as yet be estimated.

Maintenance.—The maintenance of concrete pavements consists of keeping expansion joints, center joints, and cracks filled or protected with bituminous materials, the repair of blowups and other minor failures, and the correcting of settlements and other shifting of the slab. The cost of maintenance naturally varies over a wide range, depending on the age of pavement, the quality of concrete, climatic and traffic conditions, and the thoroughness of the maintenance work. Reports from 10 representative states in 1933 on pavements ranging from one to nine years old gave maintenance costs from $53 to $205 per mile per year, with an average of $121 per mile per year on about 24,000 miles of pavement 18 and 20 ft. wide.

Mudjacking.—Owing to the settlement of the subgrade, rough and even dangerous areas frequently developed in concrete highways, especially on high fills and bridge approaches. To overcome this, gaps were left in the pavement and kept filled with stone or gravel until the fill had settled, or bituminous mixtures were placed on top of the slab to even up the surface. The process of water-soaking the fills overcame part of the trouble and mudjacking has completed the process, so that the *gravel gap* and the black-top patch are becoming things of the past.

Mudjacking[1] consists of drilling holes through the pavement and then pumping a semifluid mud through the holes under pressure. This acts like a hydraulic jack raising the slab to place, after which the mud stiffens and forms a permanent support.

The mudjack as now made consists of a combined mixer or pug-mill, driven by a gasoline engine, and mounted on wheels

[1] Devised about 1925 by John Poulter of the Iowa Highway Department.

which can be towed by a truck. The mud is made of ordinary clay or loam soils free from abrasive grit. Some soils work better than others and some knowledge is being gained in regard to the selection of suitable soils.[1]

The soil is mixed with water to a plastic semifluid consistency. From 3 to 7 percent by weight of portland cement is added to the mix for the purpose of hastening the stiffening of the mud and reducing the shrinkage as the mud dries to normal soil-moisture content. Holes about 2½ in. in diameter are drilled

FIG. 9-22.—Poulter mudjack.

through the pavement about 5 ft. apart both ways, thus making four rows in a double-lane road. For a bad settlement a relief joint 2 to 4 in. wide is cut across the pavement. The mud is pumped through a hose into the holes, and by changing from hole to hole the slabs can be brought to an even surface with remarkable ease and accuracy. The mud thoroughly fills any voids or depressions in the subgrade and gives full support to the slab. The cost is variable depending upon the area to be raised and the amount of lift. It is very much cheaper than replacing the slab, less expensive and more permanent than black top, and more economical than gravel gaps.

Cost.—The cost of a concrete pavement is not hard to estimate. The amounts of materials are quite definite and, by knowing the

[1] *Public Roads*, Vol. 14, No. 10, p. 181, December, 1933.

local prices, the cost of materials is easily and accurately figured. Labor costs vary with the local labor rates.

For the season of 1931 the bid prices in the Mississippi Valley of 7-in. concrete city pavement of 1:2:3 mix with about 5 lb. of steel mesh per sq. yd., corner reinforcement, doweled center joint, and asphalt expansion joints about 30 ft. apart ranged from $2.10 to $2.50 per square yard, with about $2.35 as a fair normal. Prices in other parts of the country were not greatly different.

Rural highways having less steel, no mesh, etc., and being somewhat thinner, showed a range of $1.40 to $2.00 per square yard for a section similar to the Illinois section or an average of about $17,000 to $19,000 per mile 18 ft. wide.

The foregoing prices are for the slab only, including materials, laying, and curing but not including any grading, drainage, or other accessories. During 1932, 1933, and 1934 prices were generally lower but they were erratic owing to general economic conditions and therefore should not be taken as typical figures.

Characteristics.—A well-laid concrete pavement is smooth, dustless, sanitary, easily cleaned, and durable. It possesses low tractive resistance combined with excellent traction. Moreover, its traction factor does not decrease appreciably when the surface is wet, which fact adds to safety, since there is less danger of skidding. The light color adds to the visibility at night which is highly desirable but sometimes causes a disagreeable glare in bright sunlight. The greatest defect of concrete from the standpoint of comfortable riding is its harshness or lack of resilience.

Concrete pavements have good life and are not difficult to maintain or repair. When the surface becomes too rough for traffic, however, the pavement must be either entirely replaced or resurfaced by adding a new layer on top. This factor of replacement or resurfacing is worthy of consideration in estimating the economic value, especially on heavily traveled streets, since it may not be practicable to add a layer of appreciable thickness to renew the surface.

MISCELLANEOUS TYPES

Cement-bound Macadam.—This is a revival of the *Hassam* pavement which was introduced about 1908. It might well be termed either a *grouted macadam* or a *penetration concrete.* Its general process of construction is quite analogous to that of

macadam. Clean broken stone, gravel, or crushed slag, ranging in size from 1½ to 3 in. and free from fine material which would prevent the entry of the grout, is placed between wood or steel forms. It may be partially compacted by rolling with a moderate-weight power roller or left loose. The depth of aggregate may be 6 to 7 in. in the middle and preferably with thickened edges. A portland-cement grout, proportioned about 1:2 by weight using sand up to ⅛ in. in size, and mixed to a *creamy* consistency is

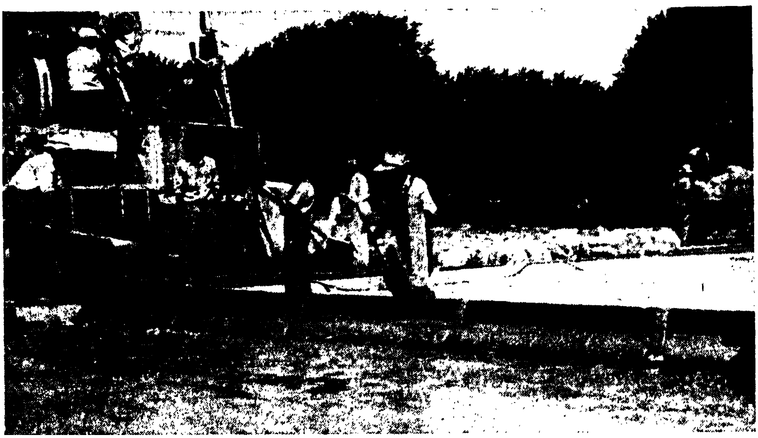


FIG. 9-23.—Cement-bound macadam. Applying the grout from a trough.

then poured on the surface and permitted to penetrate with the aid of brooming and tamping or rolling. The surface is then finished with float and belt the same as concrete. With suitable aggregates and a little care, complete penetration of the grout can be obtained with slabs as much as 10 in. thick. Expansion joints can be installed if desired, as well as other joints and reinforcement. The general characteristics are the same as concrete, except that it is not quite so smooth. It is somewhat cheaper than concrete owing to savings in details and in labor and equipment costs incident to the proportioning, mixing, and placing process of concrete. It is a question, however, whether the decrease in cost compensates for the loss in quality.

Vibrolithic.—The Vibrolithic pavement is a concrete pavement into the surface of which an additional amount of coarse aggregate of high quality has been forced for the purpose of increasing the density and wearing qualities. The slab is laid in the ordinary way and struck off to shape. Crushed granite or trap rock

of about 1-in. size is spread over the surface in an amount sufficient to load the top 1 or 2 in. of the concrete with all the coarse aggregate the mortar is capable of covering. Wood platforms, similar to inverted duck-boards are placed on the surface and the special patented Vibrolithic vibrating machines run over the platforms until the hard stone is forced into the concrete and covered with the mortar. The surface is then finished with belt and floats. Experiments have shown that this process does increase the density, strength, and wearing qualities. On the other hand, trouble has been experienced in getting a smooth, true surface of uniform character. It remains to be established that the increased benefits are worth the additional cost.

PAVEMENT BASES

A concrete pavement base is a monolithic slab provided to distribute over the subgrade the loads of traffic traveling on a superimposed wearing surface.

A concrete base is always laid in one course. Not being required to resist the direct action of traffic resistance to wear is relatively unimportant. Strength is the primary requirement.

Proportioning, Mixing, and Placing.—Basic proportions vary from 1:2:3 to 1:4:8 with 1:2½:4 or 1:3:5 the most common. The basic proportions are interrelated with the thickness as will be discussed later, while the exact proportions are often worked out by the so-called scientific methods of proportioning. The consistency should be as dry as is consistent with proper compacting and finishing.

The processes of proportioning, mixing, and placing are identical with those of the concrete pavement, and the same methods and equipment are used. More difficulty is experienced with central mixing plants, however, since the leaner mixes show more tendency to compact or segregate in hauling.

Shaping, Compacting, and Finishing.—These processes are practically the same as for concrete pavement, except that they are not quite so thoroughly done since the surface course can take up a certain amount of irregularities. Most pavement bases are prepared by hand, using the strike board or stakes and long-handled floats for shaping, the longitudinal float and roller for compacting, and the long-handled float and belt for finishing. Various forms of vibrators have also been used for compacting with good results. Straightedging is now also practiced and

there is a general trend toward better workmanship on pavement bases. The results are well worth the greater effort and the small additional cost. Machine shaping and compacting is growing in favor where conditions make it possible.

For wood block pavement, to be laid with a paint-coat cushion, the concrete base must be true to grade and cross-section. This calls for practically as careful finish as a concrete pavement.

Block pavements using a cushion may admit of some irregularities of surface of the base but these should never be large. The finished base should be free from irregularities greater than ½ in. in 10 ft. and should show no stone pockets, loose stone, or other

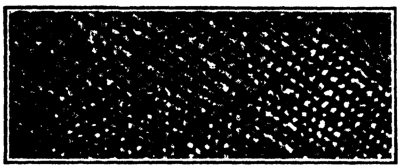


FIG. 9-24.—Rough surface of concrete base left by perforated roller suitable for bituminous wearing course.

defects. Its general appearance should be the same as a concrete pavement and its riding qualities, if traffic were permitted on it, should not be markedly different. It is by no means difficult to obtain such results and the cost is not materially increased.

Bituminous surfaces such as sheet asphalt and bituminous concrete require a roughened surface to provide bond. The concrete should be made true to crown and grade, and free from waves greater than ¼ to ½ in. in 10 ft. The surface should be roughened by raking or otherwise just before setting. The perforated roller gives an excellent bonding surface and also compacts the concrete.

Protecting and Curing.—Concrete bases should be protected and cured the same as concrete pavements. They must carry the same loads and therefore must develop their full strength.

Special curing is not often provided since the wearing surface forms a protective covering and the time elapsing between the laying of the concrete and the finishing of the surface is often curing time enough. The concrete should, however, be kept from drying out before the surface is laid. This may be done by sprinkling, by means of calcium-chloride or by placing the sand-cushion material, if such is to be used, and sprinkling occasionally in hot, dry weather until the concrete gains strength enough to

support the operations of laying the surface. Three to seven days is usually sufficient in warm weather. After the surface is laid, the pavement should be kept closed to traffic until a total curing period equal to that required for concrete pavements has elapsed. The determination of the actual curing time by means of cross-bending tests is to be recommended. Proper curing of the base has frequently been neglected.

Thickness.—The thickness of the slab is governed by the same laws as the concrete pavement.

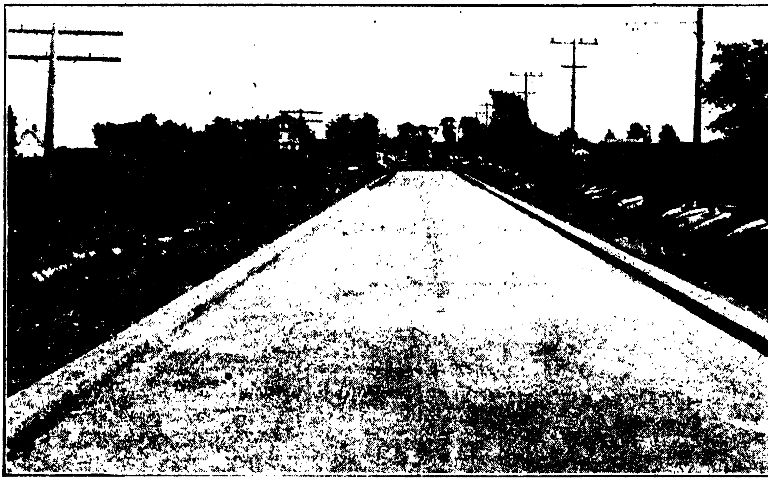


FIG. 9-25.—Finished base for brick pavement. Note the smoothness of its surface. Finished by machine and cured with calcium chloride.

The wearing surface, in view of present information, may be assumed to absorb the greater part, if not all, of the impact. In addition, the surface course distributes the wheel load over a somewhat larger area of slab. Professor Westergaard[1] has shown that this has considerable effect on the stresses in the concrete. Both of these tend to reduce the required thickness.

Temperature changes in the base are more gradual than in an exposed slab owing to protection by the wearing surface, and the differential temperatures between top and bottom are much smaller. The warping is therefore much less, with the result that the slab remains in closer contact with the subgrade and consequently receives more uniform support from it.

[1] *Proc.*, Fifth Ann. Meeting, Highway Research Board, National Research Council, Pt. 1, 1926.

Clifford Older, in his reports of the Bates road tests, gives the conclusions that, for the types of surfaces studied there, the base slab could be reduced from ½ to 1 in. in thickness below that required for a concrete pavement of the same carrying power.

By combining all these it appears logical that a concrete base does not require the same strength as an exposed slab. Advantage may be taken of this fact either by reducing the thickness and using the same concrete or by retaining the thickness and using a leaner concrete.

Using Older's formulas, the middle thickness under a load of 10,000 lb. with a working stress of 300 lb. per square inch, the thickness is

$$t = \sqrt{\frac{0.75 \times 10{,}000}{300}} = 5 \text{ in.}$$

With the assumption of a permissible reduction of 1 in. the base might be made approximately 4 in. thick if the same concrete were used.

On the other hand, if this 5-in. base is surfaced, it is equivalent to a 6-in. exposed slab. Substituting this latter figure,

$$S = \frac{0.75 \times 10{,}000}{6^2} = 208 \text{ lb. per square inch.}$$

Thus a concrete base 5 in. thick, having a safe working stress of 208 lb. per square inch when surfaced, gives a pavement equal in carrying capacity to an exposed slab 5 in. thick, having a safe stress of 300 lb.

Experience indicates that unduly thin bases offer troubles in laying and, further, that there are some advantages in dead weight of pavement. Consequently it seems better to use the greater thickness and leaner mix. The total cost is not greatly different. The ordinary minimum thickness is 6 in., with an occasional maximum of about 12 in.

Reinforcing.—Pavement bases in the past have rarely been reinforced for either temperature or load. It is quite certain that bases crack and the cracks come through to the surface. It is, therefore, logical to insert mesh reinforcing and there seems to be a trend of practice in this direction. If mesh is used, it should be designed and placed the same as in a concrete pavement.

Marginal reinforcing on rural highways and corner reinforcements wherever needed, the same as used in concrete pavements,

are also gaining favor and are to be recommended. Load reinforcement, however, is of doubtful economy since the slab cannot be reduced sufficiently in thickness to offset the cost of the steel.

Blowups.—Blowups occur occasionally owing to the same general causes as in a concrete pavement. The most prolific source of trouble in the past was the old practice of ending a day's run by feathering off the concrete in a distance of 2 or 3 ft.; and when the next day's work started, the new concrete was lapped over the old. This inclined plane of junction transformed all expansion of the slab into vertical movement and trouble resulted. The end of a run should therefore be made only at a header board

FIG. 9-26.—A base failure.

placed at right angles to the center line and perpendicular to the subgrade.

Center Joints.—Center joints have rarely been used. The decreased tendency to warp due to the protection offered by the wearing surface makes the joint less necessary. On very wide pavements, however, such joints would seem advisable, as they would tend to reduce irregular cracking.

Frequently wide bases are laid in strips. In this case tied joints should be used and the bars designed just as for the center joint. The joint plate may be omitted. The size of bars can be computed in the same way as for concrete pavements but the total weight of pavement, not that of the base alone, should be used in the calculations.

Expansion Joints.—Transverse expansion joints are rarely used. The protection offered by the surface reduces the amount of expansion, contraction, and warping. The necessity for joints

is therefore much less than in the exposed slab of the concrete pavement.

Transverse expansion joints also cause difficulties with the wearing surface. Expansion movement is concentrated at the joints, resulting in the surface heaving, cracking, etc. It is nearly impossible to put an expansion joint in the base and also in the surface so that the two will work together.

Longitudinal joints are used as occasion seems to demand.

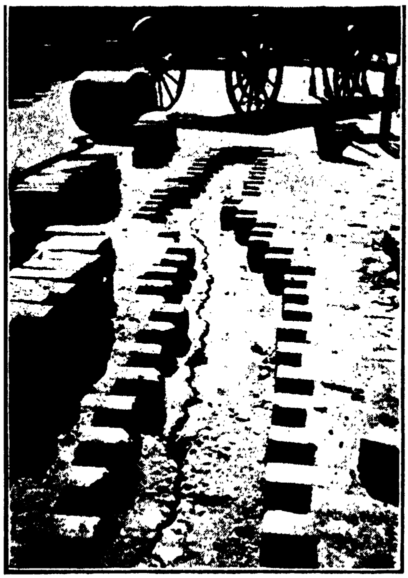


FIG. 9-27.—A crack in the base of a brick pavement. Mesh reinforcement would have prevented this crack from widening, the cushion from leaking, and the brick from settling. Repaired by cleaning out and filling with asphalt.

Cost.—The estimate of cost is comparatively definite and is made in the same way as for concrete pavements. For the conditions prevailing in 1931 the ordinary concrete base of 1:3:5 mix varied between 20 and 25 cts. per square yard per inch of thickness. The latter one is conservative for rough estimates. Later prices have been erratic and cannot be considered typical.

Problems

9-1. Two pavements 36.0 ft. wide and on straight grades intersect at 90 deg. The curb-and-gutter is 24 in. wide, the corner radii to back of curb are 15.0 ft., and the normal crown of 2½ in. is to be increased to 3 in. across the intersection. The rod readings at points *B*, *C*, *D*, and *E* in Fig. 9-10 are 4.88, 4.22, 4.53, and 5.16 ft., respectively. Compute the rod

readings for A, b, c, d, e, and a point f in each quadrant midway between A and each of the other points.

9-2. The two pavements in Prob. 9-1 intersect at 60 deg. The rod readings on the edge of gutter at the acute angles are 5.02 and 7.64, while those at the obtuse angles are 6.66 and 6.02. With other items the same as before, compute the rod readings for the five major points.

9-3. With a coefficient of expansion of 0.000006 and a temperature range of 60°, what should be the width of expansion joints spaced 33 ft. apart if the joint filler can accommodate a compression of 25 percent of its thickness?

9-4. A plain concrete slab is 20 ft. wide and 8 in. thick. If there is a difference in temperature between top and bottom of 25° and the coefficient of expansion is 0.000006, what is the theoretical amount of transverse warping?

9-5. With a coefficient of expansion of 0.000006, a coefficient of elasticity of 3,000,000, and temperature rise of 25°, what is the maximum compressive stress developed? At what distance from a free end could this occur if the coefficient of friction with the subgrade is 1.2?

9-6. A pavement slab 24 ft. wide and 8 in. thick has center-joint tie bars spaced 2½ ft. apart. With $f = 1.3$, a tensile stress in the steel of 20,000 lb. per square inch, and a bond stress of 110 lb. per square inch, what should be the proper size and length of the tie bars? (See Table 2-6.)

9-7. A pavement slab 60 ft. wide and 7 in. thick with a 24-in. curb-and-gutter tied to each edge is to be laid in three strips, each 20 ft. wide, with tied center joints, and with the strips tied together. With $f = 1.2$ and a stress in the steel of 20,000 lb. per square inch, determine the spacing of ½ in. round bars in each construction joint and each concealed joint.

9-8. Assuming the same data as in Prob. 9-7 and also that expansion joints are to be spaced 33 ft. apart, determine the size of mesh for each strip of slab (see Table 2-8).

9-9. With a working stress of 350 lb. per square inch, determine the thickness at a free corner under a wheel load including impact of 12,000 lb. by Older's method.

9-10. By Older's method determine the minimum strength required in a 9-in. doweled-edge slab for a gross wheel load of 12,000 lb.

9-11. Assuming $W = 12{,}000$ lb., $t = 9$ in., $a = 6$ in., $E = 3{,}000{,}000$, $\mu = 0.15$, and $k = 100$, compute the stress in a free corner by Westergaard's method, using both the original and the revised equations.

9-12. A slab is to have the edge thickened at a uniform rate in a distance of 2 ft. 8 in. from the edge. With a wheel load of 8,000 lb. and a stress in the concrete of 350 lb. per square inch, determine the middle and edge thickness of a doweled-edge slab under pneumatic tires, using Sheets' method.

9-13. Assuming that a brick surface will permit reducing the thickness of a concrete base by 1 in. as compared with a pavement slab, what should be the middle thickness of a 1:3:5 concrete base having a working stress of 250 lb. per square inch under a wheel load of 12,000 lb. using Older's method.

9-14. Using the data in Prob. 9-13, except changing the load to 8,000 lb., compute the thickness by Sheets' method for both pneumatic and solid tires.

CHAPTER 10

BLOCK PAVEMENTS

A block pavement is one whose wearing surface is composed of regular shaped blocks of some wear-resisting material. A block pavement is made up of three primary parts, the *base* or load-carrying element, the *cushion* or bedding course, and the *wearing surface.* The last is composed of the *blocks* and the joint *filler.*

The *base* rests directly on the subgrade and distributes the loads over a sufficient area of the soil to prevent settlement. An insufficient base is probably the cause of more block pavement failures than any other single thing (see Fig. 9-26).

The *cushion* rests on the base and carries the wearing surface. Its primary function is to take up the irregularities of the blocks so as to give each block a firm support. In addition, the cushion may introduce a degree of resilience into the pavement. The cushion should always be as uniform in thickness as possible. It must be of such a character as to bed the blocks evenly and firmly during construction and then resist displacement.

The *wearing surface* rests on the cushion and carries the traffic. The blocks are firmly bedded in the cushion by rolling or tamping. The spaces between the blocks are closed with the *filler.* The functions of the filler are to seal the joint against the entry of water and dirt, to support the block laterally, and to protect the edges of the block from damage by traffic.

Stone, wood, and brick are the most common varieties of block. Molded blocks of asphalt concrete are used to a limited extent while concrete blocks, rubber, etc., are occasionally found.

The brick pavement is the typical block pavement and constitutes by far the largest percentage of block pavements in the United States. A careful consideration of this type will, therefore, form a basis for all others.

BRICK PAVEMENT

The origin of the brick pavement is lost in antiquity. Burned clay was known prior to 4000 B.C. Brick paved courts and

drives dating earlier than 3000 B.C. have been unearthed. The Romans probably used brick for road purposes in localities where stone was scarce, just as they did for building purposes, but all direct evidence of this appears to be lost. Holland possesses some brick pavements more than one hundred and thirty years old. It is claimed that some stretches in Japan were built more than 300 years ago.

The first brick pavement in the United States is usually credited to Charleston, W. Va., in the year 1872.[1] The next year a short section was laid in Bloomington, Ill. Following years saw the rapid development of brick paving in many parts of the country.

FIG. 10-1.—Two-course brick pavement.

Development of Types.—The first brick pavements were built of hard-burned common building brick. At first the brick were simply set on edge on a bed of bank-run gravel with fine sand spread over the top to fill the joints. These pavements lacked stability and load capacity even for the traffic of those days.

The *two-course pavement* was developed to secure greater strength and stability. In this type the gravel base was retained but a first course of brick was laid flatwise on it and the joints filled with sand. A layer of sand or fine gravel 1 to 2 in. thick was placed on this course of brick and the second course of brick set edgewise and filled with sand placed on top for a wearing surface. The various courses were tamped to compact them and make the surface even. Many of these old pavements still exist and in some cases are in remarkably good condition. Many others

[1] A somewhat ambiguous statement in the "Autobiography of Benjamin Franklin" indicates that some variety of brick pavement was built in Philadelphia about 1755.

would be in fair condition today had they not been mutilated by improperly backfilled sewer, water, gas, and other trenches, most of which were cut subsequent to the building of the pavement.

Where lumber was cheap a *plank base* was sometimes employed. Earth or sand was used to level off the subgrade to receive the plank which were 2 or 3 in. thick. A sand cushion was placed on the plank and the brick laid and filled with sand. When new, these pavements were excellent but the planks decayed and the last condition was worse than the first. *Broken-stone bases* naturally developed where macadam roads were known. Old stone roads or new-laid macadam bases were covered with a sand cushion on which the bricks were laid.

Just when or where the *concrete base* was introduced is not recorded. It developed in the attempt to secure greater load-carrying capacity at lower cost. As cement became more available and lower in price, this base practically superseded all others, since greater strength could be secured at lower cost than in any other way. At first natural cement was used but with the development of the American portland-cement industry the latter came into universal use.[1] The original proportions were very lean, ranging from 1:8 to 1:16 usually with a bank-run gravel. Modern practice calls for richer mixes as shown in Chap. 9.

Sand filler was invariably used in the earlier types. Just when *bituminous fillers* were first used is not definitely known but they were developed to secure greater imperviousness and to protect the edges of the brick. *Cement grout* filler originated about 1890 for these same reasons but the fact that it changed the character of the surface into a rigid slab capable of load support and subject to expansion troubles was not appreciated for a considerable time.

Present Types.—Perhaps no other type of pavement shows as many present variations as does brick. These have all resulted from attempts to gain greater strength, to reduce the cost, or to meet certain local or technical conditions. Figure 10-2 gives in diagrammatic form the fundamental makeup of practically all

[1] J. W. Stipes claims that he laid the first brick pavement with *portland-cement* concrete base about 1898 in Champaign, Ill., after comparative tests made for him at the University of Illinois showed that a 1:12 mix of portland cement and bank-run gravel gave a stronger concrete than the usual 1:3:6 mix with natural cement.

varieties of the brick pavement. Practically all possible combinations of base, cushion, and filler shown are employed at times. Only two have specific names the others being simply described by their makeup.

Each of these varieties has certain characteristics, advantages, and disadvantages with which the engineer who expects to use them should be familiar. A careful consideration of each of the elements will aid him in evaluating each type.

- Brick pavements
  - Flexible surface or soft filler types
    - Flexible base
      - Base: Gravel; Macadam; Bituminous—black base
      - Cushion: Sand; Sand cement; Mastic
      - Filler: Sand; Asphalt or tar; Mastic
    - Rigid base
      - Base: Concrete or grouted brick
      - Cushion: Sand; Sand cement; Mastic
      - Filler: Sand; Asphalt or tar; Mastic
  - Rigid surface or hard filler types
    - Single slab
      - Flexible base
        - Base: Gravel; Macadam; Bituminous—black base
        - Cushion: Sand; Sand cement; Mastic
        - Filler: Cement grout
      - Rigid base
        - Base: None, brick on subgrade direct; Concrete or grouted brick
        - Cushion: None, brick bedded in concrete base while soft, *monolithic type*
        - Filler: Cement grout
    - Double slab
      - Base: Concrete or grouted brick
      - Cushion: Sand; Mastic (rare); Sand cement, *semi-monolithic type*
      - Filler: Cement grout

FIG. 10-2.—Classification of brick pavements.

Gravel Base.—The gravel base is used where gravel is plentiful and cheap. The thickness should probably be not less than 10 to 12 in. if the full value of the brick surface is to be gained. Its construction is identical with that of a first-class gravel road, except extra care must be taken to consolidate it thoroughly before laying the brick, as it is impracticable to do so afterwards. An old, thoroughly consolidated gravel road may be used as a base with good results, and in fact this is about the only time that

a gravel base is economical. It should be scarified, reshaped, and given time to recompact before the brick are placed. A new gravel base is rather rare in modern practice. Sand cushion and sand filler are most frequently used with a gravel base.

Macadam Base.—Macadam is economical only where stone is exceptionally plentiful and low in price. An existing road forms the best macadam base and this is about the only case where a macadam base is justifiable. The construction of a macadam base is the same as a macadam road but especial care must be taken to secure perfect work, since defects cannot be remedied after the brick are placed. A minimum thickness of 9 or 10 in. should be used if a brick surface is justifiable, since it is poor economy to lay a high-priced, high-quality surface on a poor base. A new stone base of this thickness is likely to be expensive. For these reasons modern practice shuns the macadam base. Sand cushion and sand or bituminous filler are employed with macadam base.

Black Base.—The so-called black base is either a bituminous macadam or a bituminous concrete (see Chap. 11). Either type is laid exactly the same as roads of the same type except that somewhat less binder is used and the seal coat is usually omitted. Tar or asphalt may be used for the binder. This type of base is justifiable only where stone and bituminous material are low in price, since it must be of considerable thickness to carry the loads. Its load capacity is not definitely known but may be estimated the same as ordinary macadam. Not less than 8 to 10 in. is required. As with gravel and macadam, it is doubtful whether this type of base is ever economical except where an existing road can be employed. On an existing road the *black top* may be thin so that the actual base is in reality gravel or macadam. The black base for new brick pavement is rarely seen.

Concrete Base.—The concrete base has become the standard base for brick pavements. Its high supporting power for a given thickness makes it able to compete in price with the so-called cheaper types, since it can be made thinner, thus requiring less material and less excavation. In addition it is more uniform in character and therefore more dependable. The factors of thickness, proportions, and laying are essentially the same for brick surface as for any other surface and are given in Chap. 9. The concrete base should always be finished true to crown and grade and free from irregularities, stone pockets, etc. While not requir-

ing the high finish of a concrete pavement, the truer the surface of the base the easier it is to lay a smooth, even surface and the greater will be its stability. A little extra effort and expense added to finishing the base will be well repaid.

It is especially important with brick pavements using sand cushion that cracks shall not open up in the base, since the cushion will flow into the crack and permit the bricks to depress. For this reason mesh reinforcement, center joints, etc., are occasionally found and are to be recommended. This is not so important with mastic or sand-cement cushions. In the monolithic and semi-monolithic types, cracks in the base also mean cracks in the surface, and their elimination is difficult, if not impossible. Proper design may reduce the number and adequate maintenance care for the remainder.

FIG. 10-3.—Placing sand cushion.

Sand Cushion.—The sand cushion is the oldest and the most common. A thick cushion permits easier bedding of the brick but is more difficult to compact and has a greater tendency to shift under loads, which results in an uneven surface. The thinner cushion does not require so much care in compacting, requires more effort to bed the brick, but is less likely to shift. The thickness of the cushion should therefore be the minimum consistent with thorough bedding of the brick. The thickness ranges between $\frac{3}{4}$ and $1\frac{1}{4}$ in. with 1 in. as the normal value. Formerly it was made 2 in. or more in thickness.

A coarse, well-graded sand should always be used. A good concrete sand graded in size up to $\frac{1}{4}$ in. makes the best cushion. It shifts less easily and does not leak into cracks so freely as a fine sand. It makes the bedding of the brick somewhat more difficult but is more stable than a cushion of fine sand.

The sand cushion is comparatively inexpensive, it has some resilience, is easily laid, beds the bricks well, and can easily be made smooth and free from waves. Its worst faults are shifting and leakage.

Placing the Sand Cushion.—Ordinarily the sand is dumped in piles, shoveled over the surface, struck off with a template, and the brick laid. In this case the sand is not uniformly compacted. The remains of the piles are more solid than the loose sand between, with the result that the surface is likely to be wavy. The author recalls one brick pavement where the position of every load of sand for the cushion was clearly visible in the finished surface.

Better results can be obtained by care in placing the loads and in shoveling so that each pile is completely moved, thus avoiding uneven compacting. This method is generally quite effective, inexpensive, and satisfactory. Sometimes, after the sand is spread, it is thoroughly loosened by raking or harrowing and then struck off. This gives a layer of uniform character which permits good bedding of the brick and is quite uniformly compacted by the rolling of the brick. This is probably the best method.

Another method frequently used is to spread the sand and roll it with a hand roller weighing 300 to 500 lb., after which a slight addition of sand is made and struck off. Sometimes the rolling and striking are repeated. This process gives a uniform and well-compacted cushion but since its compressibility has been reduced by the rolling it is difficult to bed the brick and, if the brick are rather irregular, perfect bedding of each brick may not be secured, unless the cushion is unduly thick.

No walking or traffic of any kind should be permitted on the cushion before the brick are laid.

Sand-cement Cushion.—The sand-cement cushion was devised in the attempt to overcome the leaking and shifting of the ordinary sand cushion. This bedding course consists of a mixture of sand and cement, usually placed dry to a thickness of about 1 in. The proportions range from 1:3 to 1:5 but 1:4 is perhaps the most common and appears to be the most satisfactory. The materials are mixed dry in a small concrete mixer and then placed the same as a sand cushion without rolling. Owing to the fact that the voids of the mixture are less than of the sand alone and also that the cement reduces the ease with which the grains move

among themselves, it is more difficult to bed the brick in a sand-cement cushion than in a sand cushion. Brick are often broken in the rolling. If the brick are not to surface after two or three passes of the roller, they cannot be made so without taking them up, loosening and adjusting the cushion, then relaying and rerolling the brick. The cushion should be loosened rather than compacted before laying the brick and a somewhat greater thickness may be desirable to give sufficient compressibility. Difficulty in bedding the brick is pronounced with a thickness less than 1 in., and greater thickness becomes expensive.

After the brick are rolled, moisture must be supplied to the cushion, usually by surface sprinkling, so that the cement will set. If a cement grout filler is employed, sprinkling is not needed, since this filler contains sufficient excess water to wet the cushion. Sprinkling always carries with it the danger of bringing the cushion up into the joints to the later exclusion of the filler. Sometimes the sand-cement cushion is mixed moist to the consistency of brown sugar, then spread, raked, and struck off. The brick must be placed and rolled to surface before the cement begins to set. Either method will give satisfactory results but the latter requires somewhat more care, for, if the batches are not uniformly moist, they will compact unevenly and make the surface rough.

The sand-cement cushion is hard and rigid. It supports the brick thoroughly but lacks resiliency. Its use with a flexible base and a soft filler is therefore rather anomalous. Combined with a concrete base and grout filler it gives the *semi-monolithic* type of pavement. Used with a concrete base and an asphalt filler it tends to reduce the resilience and the ability to take up expansion provided by this filler, and its suitability in this combination is doubtful.

Mastic Cushion.—The mastic cushion is the result of trying to overcome the shifting and leakage of the sand cushion without losing its resilience and flexibility. It consists of a mixture of well-graded sand and a bituminous binder. Either tar or asphalt may be used but the latter is the more common. The mixture should contain from 5 to 7 percent of bitumen and a somewhat finer sand than is desirable for a sand cushion is permissible.

At first hot mixes were used but at present the preference is for cold mixes using cutback asphalt or tar, or emulsified asphalt. When tar is used the suitable grades are *TCP*-1 or *TCP*-2 as

given in Table 3-3. The objection to tar is that there are indications that it tends to become brittle after an indefinite time and impart a degree of rigidity to the cushion. Light, medium, or heavy asphalt cutbacks (*RC*-1, *RC*-2, or *RC*-3, Table 3-1) are used, depending on the climatic conditions, the lighter material being used in colder weather. Asphalt emulsions have not been very successful. If the emulsion breaks too soon it is difficult to place the cushion. If it breaks too slowly it may not set properly for a long time after the brick are in place.

A mastic cushion 1 in. thick requires about 75 lb. of sand and ¾ gal. of cutback or equivalent per square yard of pavement. The mixture is spread and raked to a uniform thickness of about 1 in. and may be lightly rolled. With hot mixes the brick must be laid at once but this is not imperative with cold mixes. Since the cushion is somewhat plastic, the brick can be well bedded if rolled before the mixture has set.

The mastic cushion is resilient, carries the load well, has little tendency to shift, and does not leak. It seems almost ideal with bituminous filler. Its use with grout filler is inconsistent. Its relatively high cost tends to limit its use to the higher class jobs.

Brick.—The specific characteristics of paving brick are given in Chap. 2. Formerly the 3¾- by 4- by 8½-in. block, laid with the 4 in. depth, was almost universally used. At present (1935) the preference is for the 3- by 4- by 8½-in. size laid with a depth of 3 in. or as the so-called *vertical fiber*. The use of the 2½-in. depth has increased on account of the lower cost but the value of these thin brick in actual service has not been definitely established. For heavy-duty pavements the large blocks should be used.

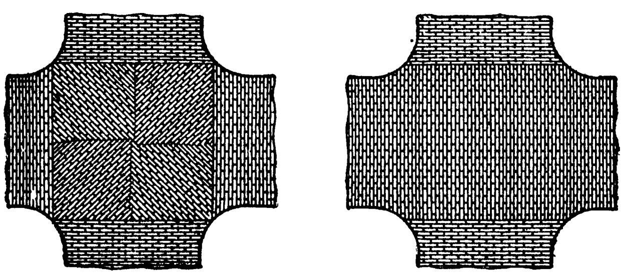
Wire-cut brick are preferred to repressed. With cement grout filler only the wire-cut lug brick should be used, since the lugs insure a joint into which the filler can enter and the adhesion of the grout to the wire-cut surface is high. Since grouted brick form essentially a concrete slab, the 4-in. depth should be used to develop as much strength as possible. With bituminous filler a lug brick should also be used, since experience has shown that complete filling of the joints cannot be obtained with plain brick. The vertical-fiber lug brick seems best to meet the requirements for the bituminous filled vertical-fiber pavements.

Laying the Brick.—The brick are laid in regular courses at right angles to the traffic. Joints should be broken in successive

courses not less than one-third the length of a brick. On curves the courses are sometimes laid longitudinally and the

FIG. 10-4.—Laying brick. Starting a dutchman.

results seem satisfactory. Ordinarily, however, the courses are kept transverse and a *dutchman* inserted at intervals to correct the curvature. The maximum angle corrected by each dutchman is about 20 deg. At intersections the old system of *double*



Double Diagonal System Through System

FIG. 10-5.—Arrangement of courses at intersections.

diagonals is giving way to placing the courses at right angles to the center line of the heavier traffic street as shown in Fig. 10-5.

With sand and bituminous fillers it is good practice to lay a course of headers along the curb and along streetcar rails, etc. This throws the irregular joints and small pieces due to *batting in* into the body of the pavement and makes a neat edge. With grout filler this is not necessary and there are some disadvantages, due to the fact that a weak, continuous, longitudinal joint is formed. Between the rails longitudinal courses are used to reduce batting.

The brick should be laid in straight courses. There is no excuse for crooked or bowed courses or for their not being at right angles to the center line. If courses begin to get crooked they may be

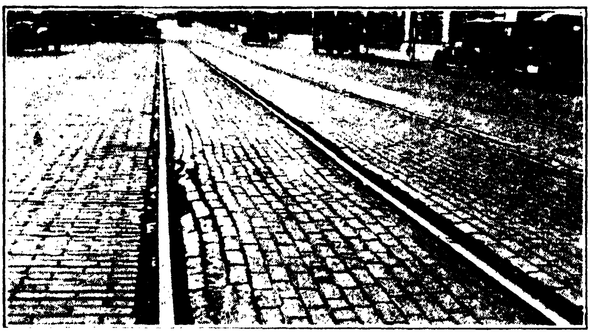


FIG. 10-6.—Longitudinal courses in street railway tracks. Note how the movement of the rails under loads has displaced the bricks, especially at the rail joints.

straightened by placing a 4 by 4 timber against the brick and driving them into line with a sledge. A good dropper, however, will keep his courses straight. The batting in should be carefully done and, if a small piece only is needed to close a course, two bricks should be cut so that no bat less than 3 in. long is used. A good dropper can lay 15,000 to 20,000 bricks per day with an assistant doing the batting. "Indian Jim" holds the record of laying 46,644 bricks in 406 min.[1]

The brick should be laid as soon as possible after the cushion is placed and all work of laying should be done from the surface of brick already laid so as to avoid disturbing the cushion.

Inspecting Brick.—In addition to the general inspection of the brick as received they should be inspected as they are laid in the pavement. The inspector should become familiar with the particular brand of brick so as to be able to identify on sight the bad brick. Many brick not suitable when whole are entirely satisfactory for batting in courses and should be so used.

[1] Dependable Highways, No. 53, September 1925.

The carriers who deliver the brick to the dropper should learn to throw out obviously unsuitable brick and also to turn the brick so that the dropper will place them in the pavement *best side up.* The dropper should not be compelled to throw out evident culls or to turn the brick. Care on these two points not only will save much trouble in changing brick afterwards but will speed up the work.

After the brick are laid and before being rolled, they should be again inspected. Bad brick should be marked to be taken out, while those which are wrong side up may be turned over. Any suitable code of marking may be used. A stick of railroad chalk in a metal ferrule on a broomstick is an excellent marking device. The inspector should go over the surface a second time after the changes are made. The brick are withdrawn by means of long-handled thin-jawed tongs.

Rolling.—After inspection, the brick should be rolled with a tandem self-propelled roller weighing not more than 5 tons except in the monolithic type of construction. A 3-ton roller is better than a heavier one, since a larger number of passes of a light roller are more effective than a few passes of a heavy one and are less likely to cause waves. A horse roller should not be used since it cannot cover the surface effectively and the horses' feet displace the brick. The rolling should be longitudinal, transverse, and diagonal if the width of pavement will permit. A narrow pavement may permit only longitudinal rolling in which case extra care must be taken to prevent waves. After the first pass of the roller the surface should be checked with a 10-ft. straightedge and depressions or humps noted. If these do not disappear under the next pass or two of the roller, they should be corrected by lifting the brick, adjusting the cushion, replacing and tamping the brick, and rechecking with the straightedge after another passage or two of the roller. The best work demands a variation of not over ⅛ in. in 10 ft. When the rolling is nearly completed the surface should be again inspected for broken brick. Any that are found should be replaced with whole brick and rolled or tamped to surface. The surface is then ready for the filler.

The monolithic construction requires special operations in laying, rolling, inspecting, and filling and will be treated later.

Sand Filler.—Sand filler is the cheapest, and the easiest and quickest to apply. Clean, well-graded sand that will pass a

$\frac{1}{8}$ screen is best. It is spread over the surface in any convenient way to a depth of about $\frac{1}{4}$ in. and permitted to work into the joints by the action of traffic and rain. The penetration may be hastened by sweeping the sand with a stiff broom or brushes worked diagonally across the joints. As soon as the sand is distributed the pavement is ready for traffic.

Bituminous Filler.—Either tar or asphalt of the types described in Chap. 3 may be used but asphalt is by far the more common. Formerly the filler was most commonly applied by being poured

FIG. 10-7.—Rolling the brick.

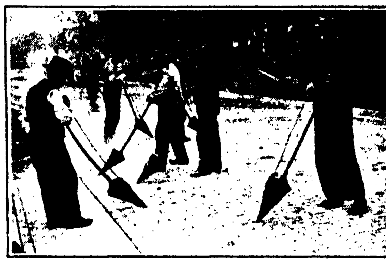


FIG. 10-8.—Applying asphalt filler with conical pouring can.

directly into the joints from *conical pouring cans* as shown in Fig. 10-8. Two or three times over the surface was necessary to secure full joints. This method secured good penetration but left irregular splotches of filler on top of the brick.

The pouring-can method was superseded by the *squeegee method* in which the hot filler is poured on the surface and swept into place by rubber-edged squeegees worked diagonally across the joints. The filler is poured out on the portion already filled and pulled out on to the unfilled portion so as to drive the air out of the joints ahead of it. Two or three times over the surface is generally necessary to fill the joints completely. The excess filler is squeegeed off, leaving only a thin layer on top of the brick. A modification of this method consists of using the squeegee buggy shown in Fig. 10-9, which both distributes the filler and works it into the joints.

As soon as the filler is applied by either of the foregoing methods, the surface is covered with clean, coarse, well-graded sand at the rate of about 15 to 20 lb. per square yard. The pavement is ready for use as soon as the filler has cooled.

The film of asphalt on top of the brick, even when well sanded, often became very slippery when wet. To overcome this, stone

chips were added, forming essentially a bituminous carpet (see Chap. 11). The result was not satisfactory since the slipperiness was not entirely cured and the carpet required continuous maintenance. From this condition developed the *surface-removal method* of applying the bituminous filler. As soon as the brick are ready for the filler, the surface is sprayed with a material which will prevent the adhesion of the filler to the brick. Whitewash (hydrated lime), sodium silicate, calcium chloride often containing about 1 percent of starch, and certain proprietary compounds are used. The amount

FIG. 10-9.—Applying asphalt filler with the squeegee buggy.

is just enough to cover the surface without running down into the joints. The filler is then applied in the usual way with squeegees or squeegee buggies, except that a little heavier coat is left on top. After the filler has partially cooled, the surface layer is peeled off, leaving the joints full but the surface bare. This should be done less than ½ hr. after applying the filler, since the separating material gradually loses its effectiveness and the filler may stick to the brick. In this way the granular surface of the brick (especially with vertical-fiber brick) which is highly antiskid is available to traffic. The filler that is peeled off is used again so that this method requires less filler than the other methods. The surface-removal method is gaining in favor and has much to recommend it.

There is a great tendency to overheat the filler since it flows more readily when hot and also cools more slowly, thus giving more time to apply it. The temperature for asphalt should never

exceed 225°C. The material should be heated slowly and carefully and maintained at these temperatures no longer than nec-

FIG. 10-10.—Surface-removal method of applying asphalt filler. The asphalt is applied generously, filling all the joints and adhering firmly to the dry sides of the brick. The separating film enables the asphalt to be easily removed from the top leaving the joints thoroughly filled and the brick surface clean.

essary. Overheating and too long heating even at a safe temperature both damage the material.

Bituminous filler is resilient and elastic. It takes up expansion and is highly waterproof. Under motor traffic it protects the edges of the bricks perfectly and under horse-drawn traffic does this reasonably well if the joints are kept full. At present it is the preferred filler. Asphalts are generally preferred to tars since they change consistency less rapidly with temperature changes. The former is termed *asphalt* filler and the latter *pitch* filler.

Mastic Filler.—Mastic filler is a mixture of fine sand and bituminous materials, usually pitch. It is applied by the squeegee method but it is difficult to get it into the narrow joints of a brick pavement and therefore it is less frequently used with brick pavement than with stone block.

Grout Filler.—Grout filler consists of an intimate mixture of fine sand, portland cement, and water. On the job the grout is often referred to as *slush* and the process as slushing.

Grout filler is hard and rigid. It cements the brick together into a solid slab which has all the characteristics of concrete.

Expansion and contraction, warping, etc., as discussed under concrete pavements (see Chap. 9) affect grout-filled brick in the same way and must be considered in designing. Formerly

TABLE 10-1.—NUMBER OF BRICK AND AMOUNT OF FILLER PER SQUARE YARD FULL JOINTS PLUS ABOUT 1/16-IN. DEPTH OVER SURFACE[1]

Size	Brick				Filler			
	Laid		Number per square yard		Gallons per square yard		Pounds per square yard specific gravity = 1.0	
	Depth	Surface	1/8-in. joints	1/4-in. joints	1/8-in. joints	1/4-in. joints	1/8-in. joints	1/4-in. joints
2 1/2 × 4 × 8 1/2	2 1/2	4 × 8 1/2	36.4	34.8	1.0	1.6	8.4	13.4
	4	2 1/2 × 8 1/2	57.2	53.8	1.8	3.0	15.0	25.0
3 × 4 × 8 1/2	3	4 × 8 1/2	36.4	34.8	1.2	1.8	10.0	15.0
	4	3 × 8 1/2	48.1	45.6	1.6	2.7	13.4	22.5
3 1/2 × 4 × 8 1/2	3 1/2	4 × 8 1/2	36.4	34.8	1.3	2.1	10.9	17.5
	4	3 1/2 × 8 1/2	41.4	39.5	1.5	2.5	12.5	20.9

[1] For the surface-removal method deduct 0.3 gal. or 2.9 lb. from the respective tabular values.

quite popular, grout filler has now largely given way to bituminous types.

The usual proportions are 1:1. A mixture leaner than 1:1½ will not work well and richer than 1:1 is unnecessary and costly. Fine sand is necessary: first, to get into the joints, and, second, to prevent segregation in the mixture. Clean silica sand that will pass a No. 8 and preferably a No. 14 sieve is best. One bag of cement will make enough 1:1 grout to fill 5 to 6 sq. yd. of 4 in. wire-cut lug brick.

The cement and sand are mixed dry and then water added and thoroughly stirred until a consistency about like good paint is obtained for the first application. For the second application a somewhat thicker consistency is desired. For finishing, the consistency should be that of thin mortar. The grout is mixed by hand in special boxes with unequal legs to run the grout to the corner or in special mixers. The batches consist of 1 sack of cement to 1 cu. ft. of sand. Large batches are avoided on account of the danger of segregation.

The mixture is poured onto the surface and spread with rubber squeegees the same as bituminous filler, constantly working off of the filled portion on to the unfilled portion in order to drive out the air. The joints are filled practically full at the first

application. For a short time, owing to absorption of water by the cushion and brick and to evaporation, the filler settles in the joints. A second application of a thicker consistency is then made in exactly the same way. About the time the cement begins to set, the final operation is made with a stiff consistency and the excess filler squeegeed off. Usually there is a sufficient filler on the surface to complete the filling, but light sprinkling may be necessary to make it workable. Figure 10-11 shows the stages in the application of grout filler.

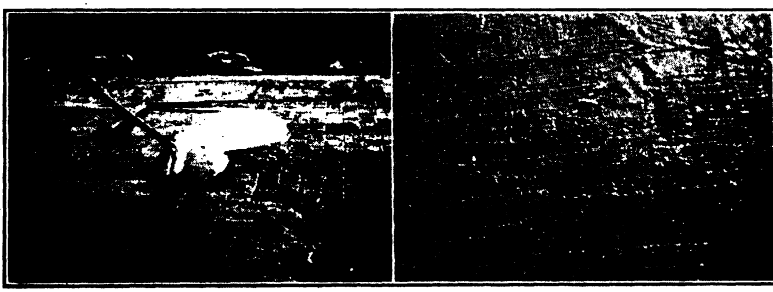
Successful Grouting.—The success of grout filler depends absolutely on securing the complete filling of the joints. If for any reason the joints are not full, trouble is sure to develop later. Only wire-cut-lug brick should be used. Care must be taken to prevent the cushion from crawling up into the joints and the process of filling must be correct. The two most common causes of defective grouting are sand or dirt in the joints, and imperfect filling of the joints. Imperfect filling is almost invariably due to carrying the stiff second application ahead of the first, thus air-binding the joints, which results in the tops being full while the bottoms or middles are empty.

It has been common practice to sprinkle the brick just prior to grouting. This is not necessary since the absorption of paving brick is so slight and so slow that there is no danger of too much water being absorbed from the grout. In fact, sprinkling is objectionable: first, because it is the most common cause of the sand cushion working up between the brick. Second, the grout contains a large excess of water and the water sprinkled on to the brick only adds that much to the quantity to be absorbed or evaporated. Third, with the surface pores of the brick filled with water the grout cannot get into contact with the brick until this water is absorbed by the brick or mixed with the grout. With dry brick the slight absorption draws the cement into the surface roughness, giving closer bond. Tests at the University of Illinois in 1917 showed a tensile bond for dry brick about 30 percent stronger than for brick sprinkled just before grouting.

Sand-cement cushions require water but sprinkling is not necessary since the grout contains sufficient water. Furthermore, this form of cushion may be brought up into the joints in the same way as the sand cushion and is practically as objectionable as the sand. Therefore, sprinkling should not be done.

A. First application. Note the mixer and brooms.

B. After the first coat. Note the joints nearly full.



C. Second application. Note the consistency and the squeegees.

D. After the second coat. Note the excess.

***E*. Finishing.** Pushing the excess grout off the surface.

F. The finished job. Note the even surface.

FIG. 10-11.—Applying cement grout filler.

Rain also causes the cushion to rise in the joints. If a rain occurs after the brick are laid and before they are grouted, it is almost invariably necessary to take up the brick, relevel the cushion, and relay the brick if good grouting is to be secured.

Curing Grout Filler.—Grout filler must have a curing period in order to gain strength. Rarely, if ever, has grout filler been properly cured. The very rich mix gains strength quickly and therefore the curing period may be cut down to 7 to 10 days in warm weather. Protection from evaporation is essential, however, and herein is the most common defect in the curing of grouted brick. The rapid scaling of the surface grout can usually

FIG. 10-12.—Defective grouting and its effect.

be traced to its drying out before properly hardening. Grout-filled brick is essentially concrete and should be cured in a like manner.

Monolithic Construction.—In 1914 Allen J. Parrish, a contractor of Paris, Ill., obtained permission from the Illinois Highway Department to construct a trial section of pavement with the brick laid directly on the fresh concrete base. The method employed was essentially as follows:

A double-bladed steel template was mounted on rollers so as to travel on the side forms. The template was pulled by the mixer. The forward blade of the template cut the fresh concrete to shape and height. The second blade, set about $\frac{3}{16}$ in. higher, served to spread over the concrete and strike off to surface a thin layer of dry mix of cement and sand piled between the blades. This thin layer was for the purpose of filling up the irregularities of the concrete and make a smooth bed for the brick. The brick were then laid, inspected, and rolled with a hand roller. Grout filler was then applied. The whole operation was carried on in

a short space so as to be completed before the cement in the base had set.

This piece of pavement appeared so successful[1] and seemed to have so many advantages that the type rapidly became popular. The method of construction outlined above was almost universally used.

Defects of the Monolithic Type.—After some experience and also experiments, two primary difficulties with the monolithic type, made as outlined above, became evident. First, the use of the dry mix under the brick formed a plane of weakness. Not being wet mixed, it was considerably weaker than the mortar in the concrete even of the same proportions, and not being wet puddled against the brick, the bond was weak. Under stresses due to load and to expansion and contraction, the brick and concrete slabs would separate. This resulted in greatly reduced strength since there resulted two slabs superimposed instead of a single slab equal to the total thickness. This made conditions favorable for traffic failures and blowups, both of which were frequent. To overcome this fault the practice developed of omitting the dry mix, semifinishing the base, then laying the brick on and rolling them into the wet mortar of the fresh concrete. Where this was done, little or no difficulty was experienced with separation.

The second primary fault of the monolithic type was that it appeared almost impossible to make it satisfactorily smooth. This was due in part to certain intrinsic difficulties and in part to the unwillingness of contractors and engineers to modify the time-honored methods of laying brick pavements to meet the peculiar needs of the new type. Part of the roughness was due to weak side forms but the greater part was due to the fact that the concrete could not be mixed to the same consistency. Unless the batches were exactly uniform, the brick could not be brought to an even surface. The roughness of the monolithic pavement is not due to the irregularities of the individual brick but to the fact that the surface is a succession of humps and hollows caused by unequal compacting and shrinkage of the concrete base course. This fault of roughness, combined with the fact that the monolithic construction did not result in a material reduction of cost as was expected, has led to the almost complete abandonment of this type.

[1] It was in excellent condition in 1934 after 20 years of service.

Semi-monolithic Construction.—This type of construction, *viz.*, grout-filled brick on a sand-cement cushion and a concrete foundation, antedates the monolithic except for its name. The term *semi-monolithic* was derived from *monolithic* to distinguish and contrast between these two types. The semi-monolithic shares many of the characteristics of the monolithic as to rigidity, expansion, blowups, etc., but differs in that it can easily be made smooth the same as any other cushion type.

Cost.—The cost of brick pavements varies greatly owing to the differences in types of construction and the prices of labor.

FIG. 10-13.—A blowup of grout-filled brick at a raised crossing.

For a 6-in. concrete base of 1:3:5 mix, a 1-in. sand cushion and vertical fiber brick with asphalt filler, prices in 1934 averaged in the neighborhood of $3.75 at a base labor price of 40 cts. per hour. Lighter construction or more favorable prices of materials might bring the price down to $3 or adverse factors raise it to $4.50. Heavier construction might run in excess of $5 per square yard. For rough estimates $3.75 for 3-in. brick and $4 for 4-in. brick may be used.

Characteristics.—Brick pavements when well laid are smooth, dustless, easily cleaned, quiet, and durable and, with the exception of the grout-filled types, are resilient. The color is dark, which may be objectionable on unlighted highways. The maintenance is not difficult or expensive and renewal of the surface is easily and economically done by removing the old brick and replacement with new. Repairs are easily made. On the whole, the brick pavement with asphalt filler is unusually well adapted to city streets, since it possesses many desirable qualities,

is moderate in price, low in upkeep, and, especially, is nearly foolproof, requiring the minimum technical care in supervision, construction, or maintenance.

STONE BLOCK

A stone block pavement is one whose wearing surface is composed of blocks of natural stone. Usually a stone block pavement is designated by the kind of stone used, such as *granite block*, *sandstone block*, etc.

A *cobblestone* pavement is one in which the surface is made up of natural boulders 6 to 10 in. in diameter. This pavement is extremely rough and unsanitary and is now obsolete in American practice. Ordinary stone block pavements are frequently called cobblestone, especially after the edges of the blocks wear and become rounded.

The Blocks.—Various stones have been used in the past but at present granite and sandstone are almost the only stones used. The blocks are split to desired size and shape as given in Chap. 2. On account of the cost, stone block is only used under the extremes of traffic such as warehouse, factory, dock, and freight-yard drives. They are occasionally used on trunk highways where prices are favorable. In these cases the blocks are often smaller in size, approaching the cubes of Durax, mentioned later.

Base.—Concrete is almost invariably used as a base. Since stone blocks are justifiable only under the extremes of traffic, the base must be correspondingly heavy, 6 in. being the minimum and as much as 12 in. being sometimes used. Reinforcing in any form is rarely used but might be desirable for the same reasons as with brick pavement, especially with the smaller block.

Cushion.—Sand is almost invariably used on account of cost. Coarse sand, however, should be employed instead of the fine sand so often seen. The cushion must be thick, owing to the great variation in the blocks. The more regular the blocks, the thinner the cushion should be. About 1½ in. is the minimum and 3 in. the maximum with 2½ in. as the average.

Filler.—Sand, grout, and bituminous filler are all employed. The first is now rarely used, and the second is not so popular as a few years ago. Owing to the wide joints, a large amount of filler is required and is therefore expensive. To reduce the cost, tar mastic is often used and is quite satisfactory. With asphalt filler it is quite usual first to apply pea gravel, removing any excess

on the surface, and then to apply the asphalt. This reduces the amount of asphalt required and adds to the stability of the filler in the wide joints. The characteristics and behavior of any of these fillers are exactly the same as with brick.

Blocks averaging about 4 in. wide, 10 in. long, and 5 in. deep will require from 4½ to 5 gal. of filler per square yard. The amount of filler will change between ¾ and 1 gal. per square yard for a change of 1 in. in the depth of block. This allows for a film coating the surface. The surface-removal method has not been applied to stone block.

Laying.—The base is laid and cured exactly the same as for any other surface and the cushion is spread and struck off as for brick.

The blocks are laid in regular courses as are brick. Owing to the greater variation in depth of the block, they must usually be laid individually. That is, instead of them being simply dropped on to the cushion, the cushion is scooped out with a special trowel and each block set in place flush with those adjacent. The laying of stone blocks is thus much slower than brick. Joints should break at least 3 in. and block of the same width should be chosen for each course to reduce the size of joints. After being laid, the blocks are inspected, rolled, and filled the same as brick. Small blocks and Durax cubes may be sufficiently regular in shape to be laid in the same way as brick, thus reducing the cost.

Characteristics.—A stone block pavement is almost sure to be somewhat rougher than brick but it can be made free from waves. With grout filler a concrete is formed with all the expansion and other trouble inherent thereto. The grout, however, protects and supports the edges so that the blocks rarely become cobbled. Sand filler permits the blocks to spall and wear, although this is not so serious as formerly, with the decrease in horse-drawn, steel-tired vehicles. Bituminous fillers give a smooth resilient surface. Under motor traffic they protect the edges well if the joints are kept full. Proper maintenance is therefore essential.

Durax.—Durax is a type of stone block pavement made up of cubes about 3 in. on a side. Granite is almost universally used. The blocks are laid on a sand cushion about 1½ in. thick, usually in a succession of short, curved courses and rolled or tamped to surface. Grout or bituminous filler is used. This pavement has been rather freely used in Europe, especially Germany, where it is termed *Kleinpflaster*. In the United States its use is

limited, being most frequently employed along street railway tracks. The Durax cube, however, has demonstrated the feasibility of smaller block; consequently small block pavements are gaining favor, especially as the cost is reduced by the lower cost of the block, the greater speed and lower cost of laying, and the saving in excavation.

Cost.—Stone block is the most expensive type of pavement. It is always thicker than other types and therefore requires more material, which adds to the cost. In addition, the blocks themselves are expensive and the cost of laying is higher than other kinds of blocks. In general, stone block pavements range from $5 to $10 per square yard, with $7.50 a rough average figure. The smaller block, especially the cubes, bring the cost down into the range of brick. Owing to the weight of the standard blocks, freight charges, except by water, often make the cost prohibitive except near the quarries.

WOOD BLOCK

Wood block pavement is one having a wearing surface of blocks of wood.

The Blocks.—Almost all varieties of wood have been used but long-leaf yellow pine and Douglas fir have been found the most satisfactory.

In the early days, untreated timber was used but rapid decay soon ruined the surface so that, at present, treated wood only is used. The treatment is usually with creosote although occasionally other processes are used. The normal treatment is at the rate of about 16 lb. per cubic foot. Less than this is hardly enough to protect the wood properly and more is likely to bleed objectionably.

The blocks are usually about 8 in. long and 4 in. wide and 2½, 3, 3½, or 4 in. in depth. The 3-in. depth is probably the most common but deeper block should be used on heavy-traffic streets. The blocks are so cut that the grain of the wood is vertical in the pavement. Most blocks are plain but some manufacturers supply blocks with grooves, ridges, or both, to space the joints and take up expansion.

The Base.—A concrete base should always be used for wood blocks. Sometimes other bases are employed, more especially where an existing road or pavement is to be used as a base.

If a sand or sand-cement cushion is used, the base may be given ordinary finish. If the blocks are to be placed directly on the concrete as outlined below, the base must be brought exactly to crown and grade and must be well finished. The finish in this case should be practically the same as for a concrete pavement except for such refinements as brooming and edging.

Cushion.—Sand cushion has often been used but it is rarely satisfactory. The blocks are so light that they are easily displaced by traffic, and water in the cushion may lift them. Wood block surfaces have been actually floated by water getting under the blocks.

FIG. 10-14.—Applying tar paint-coat cushion for wood-block pavement.

A sand-cement cushion is superior to sand alone since it does not shift, beds the blocks well, and tends to keep water from getting under them. The worst difficulty is to get water to the cement. Sprinkling is objectionable as it wets the blocks and they must dry before the filler can be applied. The use of a moist mix rather than a dry mix overcomes this difficulty but it is more difficult to place. The blocks themselves are sufficiently elastic and resilient to compensate for the rigidity of the cushion.

The mastic cushion is well adapted to wood blocks. It is elastic, does not shift or leak, and is quite effective in keeping out water. For creosoted block a tar binder is preferable to an asphalt binder.

The bituminous paint-coat cushion is a comparatively recent development and forms the greatest variation in construction from the brick pavement. The concrete base must be smoothly finished and exactly parallel to the finished surface of the pavement. A coat of hot bituminous cement is applied to a depth of about 1/8 in., which requires about 0.7 gal. per square yard. While the bitumen is still soft the blocks are laid and rolled. This process seals or cements the blocks to the base in such a manner that water cannot get under them, and they are moved with difficulty. The cost is about the same as for sand-cement for, while materials and labor for the cushion are less, more work must

be done in finishing the base. Either asphalt or tar may be used but a high-carbon, high-melting-point tar is the best with creosoted blocks as it is more homogeneous with the material used in treating the blocks. The asphalt should have a penetration between 60 and 80.

Filler.—Bituminous filler should always be used with treated wood blocks. Sand is not satisfactory and grout is not adapted to the thin joints. Asphalt or tar may be used. Tar is preferable for creosoted blocks since it is more closely related to the tar distillate (creosote oil) used in treating the blocks and therefore suffers less from an admixture of the latter. A high-carbon tar with melting point (cube-in-water method) of about 75°C. will give the best results. The filler should be applied by the squeegee method, filling the joints a little less than full and removing all the free filler possible from the tops of the blocks. An excess of filler is objectionable because it softens in hot weather; and if the blocks bleed even slightly, there results a sticky coating on the surface which is disliked by motorists and is a nuisance to pedestrians.

After the filler is applied it should be covered with a thin layer of fine stone chips. These serve to take up the excess filler and form a gritty surface. In time, traffic will force the stone particles into the wood which aids in reducing the slipperiness of the surface. The practice in many European cities and a few American cities is to give the wood block pavement a light surface treatment of tar covered generously with stone chips at intervals of one to three years. This keeps the blocks and joints sealed against water and maintains a somewhat gritty surface which is less slippery than the ordinary wood block pavement when wet.

Expansion.—Perhaps the greatest trouble with wood blocks is due to expansion. Temperature effects are negligible but moisture expansion is often destructive. When laid, the blocks are more or less dry as the result of treatment and storage. In the pavement they are sure to take up water and swell.

Provision for expansion is sometimes made by placing expansion joints at intervals of 10 to 30 ft. This works well with sand cushion only. With sand-cement, mastic, or paint-coat cushion, the blocks should be able to expand individually without changing position. This means that each joint must provide for expansion. Sometimes simply taking care to lay the blocks

loosely will suffice. Occasionally a metal spacer is used and removed after the blocks are laid. A very effective and inexpensive method is to use a strip of corrugated paper about 1½ in. wide as a spacer.[1] The paper is cheap, easily installed, compressible, and does not interfere with the entry of the filler. Lug blocks are effective in providing for expansion but, if the lug is in the form of a continuous bead, trouble due to air binding may be experienced in applying the filler.

FIG. 10-15.—Placing wood block between car-track rails and using corrugated-paper spacer.

Characteristics.—A wood block pavement is smooth, resilient, noiseless, sanitary, and easily cleaned. It has low tractive resistance and when dry gives good traction but may become very slippery when wet unless stone chips are freely used on the surface. Maintenance and repairs are not difficult. The block will wear indefinitely and if well treated will resist decay for a long time. A periodic treatment at intervals of 1 to 3 years of about ⅛ gal. per square yard of filler, followed by coarse sand or fine stone chips, will keep the surface sealed, tend to reduce slipperiness, and greatly prolong the life.

Wood block pavement, exclusive of base and cushion, weighs about 45 lb. per square yard per inch of thickness.

Cost.—Owing to the growing scarcity of timber and the consequent high cost, wood block pavements are becoming prohibitive in price except where the factor of weight, as, for example, on bridge floors, is important. Formerly they could be laid in competitive locations at an advance of about 10 to 20

[1] Devised by J. S. Crandell, formerly consulting highway engineer of the Barrett Company.

percent over brick. The increase in cost of all timber has shown a marked advance in the price of wood block pavement. In 1934, 3-in. wood block on a 6-in. concrete base ranged from $4.50 to $7.

Factory Floors.—Creosoted wood blocks make an extremely serviceable and satisfactory floor for factories. Such a floor is smooth, sanitary, and resilient. It is easy on the feet of the workmen and on tools and equipment. Blocks treated by the empty cell process with 4 to 8 lb. of creosote per cubic foot are generally used. The usual depth is 2½ or 3 in.

The blocks should be laid on a tar paint-coat cushion. In contrast to street pavement, however, no provision for expansion is made in the floor itself. The blocks are placed as close together as possible, and after every six to eight courses a striking piece is laid against them and the blocks driven up tight with a sledge. This makes it impossible to fill the joints in the usual way. The method of filling the joints is to dip one side and end of each block in hot tar as it is being laid.

Although no provision for expansion is made in the floor itself, an expansion joint must be placed between the blocks and the walls or columns supporting the building. These joints may be 2 to 3 in. wide and filled with prepared expansion joint filler, or they may be 3 to 4 in. wide and filled with a tar mastic. Some swelling of the wood is sure to take place and, unless these expansions spaces are provided, trouble will develop either in the floor or in the building structure.

Owing to the many satisfactory qualities, such floors have been increasing in popularity in many different kinds of factories, despite their high cost.

ASPHALT BLOCKS

An asphalt block pavement is one with a wearing surface of blocks of compressed asphalt concrete.

The blocks are made of an asphalt concrete with a well-graded aggregate similar to old Bitulithic compressed under high pressure. Table 10-2 gives the usual sizes, weights, and quantities required.

Base and Cushion.—A concrete base should be employed on new work but old bases of all kinds may be used in resurfacing.

Since the blocks are very uniform in thickness, it would seem that the best bedding course on new work would be an asphalt paint coat on a carefully finished base. The Asphalt Institute,

however, recommends a sand-cement bed about ¼ in. thick with proportions of 1:2½ to 1:3 mixed to a barely moist condition. A bedding course of this type of sufficient thickness to take up the irregularities of the old pavement should be used in resurfacing with asphalt block.

TABLE 10-2.—ASPHALT BLOCKS—WEIGHTS AND QUANTITIES

Size, inches	Weight, pounds Per block	Weight, pounds Per square yard	Blocks per square yard	Square yards per thousand blocks	Weight per thousand blocks, tons
5 by 12 by 3	15.8	341	21.5	47.0	7.93
5 by 12 by 2½	13.5	290	21.5	47.0	6.75
5 by 12 by 2	10.6	228	21.5	47.0	5.30
8 by 4 by 1¼	3.5	140	40.0	25.0	1.75

Laying.—The general process of laying is similar to that of brick except that greater care is taken to drive the blocks tight together so as to reduce the joints to a minimum. The best filler appears to be a quick-breaking asphalt emulsion containing 40 to 45 percent of water to give it high fluidity. About ⅓ gal. per square yard is required and is best applied with the squeegee buggy. As much of the filler as possible is removed from the surface. Before the emulsion sets, a thin layer of clean, fine sand is evenly broomed over the surface.

A so-called non-skid surface is made by separating the courses about ⅜ in. and then using a 1:1½ portland-cement grout filler which is raked out of the joints to a depth of about ½ in. just before it sets. This gives a succession of transverse grooves. This method might be acceptable under horse-drawn traffic but its desirability for motor traffic is decidedly questionable.

Characteristics.—A well-laid asphalt block pavement gives essentially an asphalt concrete surface. The use of blocks makes it possible to lay such a pavement in small areas or in locations where an asphalt plant is not available or economical. Asphalt blocks are not widely used.

MISCELLANEOUS

Concrete Block.—Molded blocks of concrete have been tried but, in general, are not economical. On account of their light

color, however, blocks or bricks of concrete are sometimes used to mark traffic lines, safety zones, etc. The proportions should be quite rich. Mortar brick should be 1:1½ and concrete blocks 1:1½:2½ to 1:2:3. They should be plastic molded and thoroughly cured.

In 1934 some sections of *granite-faced* blocks were laid. The blocks were 12 by 12 by 5 in. with the top 1½ in. of a rich mix using granite aggregate. The blocks were laid on a 1-in. sand-cement bed and the joints filled with asphalt. The ultimate serviceability and economy of this construction have not, as yet, been demonstrated.

Rubber Block.—Molded blocks of rubber have been tried where elasticity, freedom from noise, and low weight were required. The cost is prohibitive in large quantities. One of the most interesting instances of their use is on the Michigan Avenue Link Bridge, Chicago.

Rare Types.—A few isolated trials of blocks made of cast iron,[1] reheated glass, compressed fiber, and some other materials have been made. In general their application has been to some local condition and neither the characteristics nor the suitability of such blocks are yet known.

Plank Roads.—In the early days plank roads were built. The planks were about 3 in. thick and were laid transversely on longitudinal stringers. Earth shoulders were used and sometimes the ends of the planks were ballasted with earth or gravel. Such roads are now known only in lumber districts or on construction work.

Corduroy.—Corduroy roads are made by placing logs transversely on the road, building up to the required height with successive layers, and filling in between the larger logs with smaller logs and poles. The ends of the logs are sometimes ballasted with earth. Such roads are made only for temporary use in wooded and swampy land, for construction roads, emergency repairs, or military operations.

Problems

10-1. How many vertical-fiber brick 3 by 4 by 8½ in. with ⅛-in. joints will be required for ½ mile of pavement 36 ft. wide, allowing 5 percent for culls and batting? How many carloads?

[1] Cast Iron Block Pavement at Wilmington, Delaware, *Engineering News-Record*, Vol. 114, No. 9, p. 317, Feb. 28, 1935.

10-2. If oil asphalt costs $26 per ton delivered on the job, while heating and applying cost 1¾ cts. per gallon, what will the filler cost for the pavement in Prob. 10-1?

10-3. If 3½- by 4- by 8½-in. wire-cut lug brick laid 4 in. deep had been used in Prob. 10-1, how many would have been required? How many carloads?

10-4. A 1:1 cement grout filler is to be used in Prob. 10-3. How much sand and cement will be required? How many carloads of each?

10-5. How much sand would be required for a cushion 1 in. thick in the preceding problems?

10-6. If a mastic cushion ¾ in. thick and containing 7 percent by weight of asphalt cutback is to be used, how much of each material is required?

10-7. If granite blocks averaging 4 by 5 by 12 in. are laid 5 in. deep with ½-in. joints what will be the average number per square yard of surface? What will be the weight per block and per square yard?

10-8. How much tar and sand per square yard will be required for a mastic filler in Prob. 10-7, assuming equal parts by volume of the tar and a sand containing 40 percent voids and allowing an average of ⅛ in. of filler over the top of the blocks?

10-9. How many creosoted wood blocks will be required for a bridge floor 36 ft. wide and 725 ft. long? If the floor is 3 in. thick, what will be the total weight?

10-10. How many asphalt blocks will be required for 10,000 sq. yd. of pavement? What will they weigh for a depth of 2½ in.?

CHAPTER 11

BITUMINOUS SURFACES

A bituminous surface is one composed of a mineral aggregate held together by a bituminous binder. Such surfaces range from simple surface treatments through many intermediate forms to complex pavements.

- Bituminous surfaces
  - Blotter types
    - Surface treatments
    - Carpets
    - Seal coats
    - Skin treatments
  - Mulch types
    - Wisconsin treatment
    - Asphalt mulches
    - Oil-sand mats
  - Penetration types
    - Bituminous macadam
    - Mastic macadam
  - Mixed-in-place types
    - Tar retread
    - Asphalt surfaces
  - Road-mixed types
    - Asphalt mixtures
    - Tar mixtures
  - Plant-mixed types
    - Sheet asphalt
    - Bituminous concrete
      - Fine graded
      - Coarse graded
      - Warrenite-Bitulithic

FIG. 11-1.—Bituminous surfaces.

All bituminous surfaces belong to either of two groups, depending on whether the binder is an *asphalt* or a *tar*. They are also divided into two additional groups, depending on whether the binder must be used *hot* or is so prepared that it can be used *cold*, *i.e.*, at ordinary temperatures. In addition, bituminous surfaces may be divided into a number of groups based on the methods of construction. There are no sharp dividing lines between these groups. Even the names are not fixed, the same word meaning a different thing in different places. Moreover, each type has a number of variations and new modifications are constantly appearing. Figure 11-1 gives a classification that is generally

acceptable. It shows the principal types and the basic representative of each.

BLOTTER TYPES

A blotter type may be defined as one formed by applying a bituminous binder to an existing surface where it is absorbed by the material in place or taken up by new aggregate placed on top of it. This process forms a thin protective covering which resists wear, prevents dust, and waterproofs the surface. It may require more or less frequent renewal.

Surface Treatments.—Surface treatments may be applied to almost any kind of existing surface but are generally limited to those having an earth, gravel, stone, or bituminous top. The method of treatment varies somewhat with the character of material to which it is applied.

Earth.—Oiled earth roads are properly classified as bituminous treatments but, owing to their close relationship, both by character and by administration, to the earth road they are discussed in Chap. 7.

Gravel.—Under moderate traffic an untreated gravel road is fairly easy and not unduly expensive to maintain. Under denser traffic, however, dust becomes a nuisance, and maintenance is difficult and expensive. A treatment may then be advisable to prevent dust and reduce wear.

The surface should be smooth and firm. In case it is rough and uneven, it should be lightly scarified, reshaped with a blade, and recompacted, generally by blading and traffic although a roller may be used. Just before treating the dust should be removed by sweeping or with a blade, since it interferes with the penetration of the bitumen. This is especially true with emulsions. A liquid asphalt or tar of the grade shown in Tables 3-1 and 3-3 or a medium-breaking emulsion of high-penetration asphalt may be used for cold treatments. From 0.25 to 0.5 gal. per square yard is applied by means of a pressure distributer. The smaller quantity is suitable for dense, smooth surfaces and the larger amount for rougher or more porous ones. More than this latter quantity applied at one time will run off the surface. If a heavy treatment is desired it should be made in two applications with a sufficient interval between for the first one to be taken up. As soon as the binder is applied, the surface should be evenly covered with from 8 to 15 lb. per square yard of

coarse sand, small pea gravel, or stone chips, depending on the amount of bituminous material used. If such cover is not available the dust or fine material removed by the scraper may be used.

Hot applications are sometimes made, using a semisolid tar or asphalt. These materials require heating to 60 to 80°C. to make them fluid, but otherwise the process is the same. In cold weather the cutbacks may be warmed to help them work better.

A well-treated surface will be smooth, resilient, and dustless. It may be expected to last from 1 to 2 years under a considerable volume of light-weight traffic but may be speedily destroyed by heavy trucks.

Macadam.—Owing to the denser surface the bituminous material does not penetrate into macadam as readily as into gravel and therefore somewhat heavier amounts of cover material

TABLE 11-1.—MATERIALS FOR SURFACE TREATMENT

Surface	Bituminous material			Covering	
	Kind	Character	Gallons per square yard	Kind	Pounds per square yard
Earth	Cracked residue	Viscosity Furol, 80 to 370 at 122°F.	$\frac{1}{2}$ to $\frac{3}{4}$	Dust, sand, or pea gravel	0 to 15
Gravel	Tar	Table 3-3	$\frac{3}{8}$ to $\frac{1}{2}$	Sand or pea gravel	10 to 20
Gravel	Asphaltic	Table 3-1 or medium-breaking emulsion	$\frac{3}{8}$ to $\frac{1}{2}$	Sand or pea gravel	10 to 20
Macadam	Tar	Table 3-3	$\frac{1}{4}$ to $\frac{1}{2}$	Stone chips	15 to 30
Macadam	Asphaltic	Table 3-1 or medium-breaking emulsion	$\frac{1}{4}$ to $\frac{1}{2}$	Stone chips	15 to 30
Bituminous macadam, bituminous concrete, sheet asphalt, wood block.	Asphaltic	Table 3-1 or medium-breaking emulsion	$\frac{1}{8}$ to $\frac{3}{16}$	Sand, fine stone chips	10 to 12

may be necessary. The surface must be smooth, dry, and free from pot-holes. Scarifying, reshaping, and rolling may be necessary. This usually calls for some new fine material to true up and rebind the surface. Immediately preceding the treatment the surface should be swept free from dust. The same kinds of bituminous materials in about the same quantities

are used as on gravel. As soon as the bitumen is applied, stone chips should be applied at the rate of 12 to 16 lb. per square yard. Rolling with a light roller is desirable and generally done, additional cover being applied on spots where the binder shows through too freely. The finished surface should show the stone chips imbedded in but not covered with bitumen. The character and life of the surface are about the same as obtained on gravel.

Bituminous Surfaces.—Existing bituminous surfaces of all kinds often become dry and begin to disintegrate owing to the evaporation of the light oils from the binder. This condition can be remedied by a surface treatment sometimes termed a paint coat. An asphalt or tar corresponding to the existing binder should be used (see Table 3-3 for the tar products to be used on tar-bound pavements). Liquid asphalts, as shown in Table 3-1, or soft carpeting mediums, are used on pavements with asphaltic binders. A medium-breaking emulsion may also be used.

The surface must be swept clean and actual holes patched. The binder is then applied at the rate of about 1/8 to 3/16 gal. per square yard. More than this will run off. The surface is then covered with coarse sand or fine stone chips at the rate of about 10 to 12 lb. per square yard. On sheet asphalt and similar surfaces a clean sand passing a 1/8-in. sieve and free from an excess of fine particles should be used.

This form of treatment gives a renewed surface partly due to the new material and partly due to the fact that the existing binder absorbs some of the lighter oils from the new and its life is thereby renewed.

Cost.—The total cost varies with the work required for preparation and the cost of materials. On gravel and macadam the cost of preparation may vary from 5 cts. or more to less than 1 ct. per square yard. On bituminous surface the preparation exclusive of patching will ordinarily be 1/2 to 1 ct. per square yard.

Cutback asphalts could be obtained in 1934 for 8 to 12 cts. per gallon in tank cars, f.o.b. the nearest railroad siding. Mexican and similar asphaltic oils and tars ranged from 9 to 15 cts., and emulsions from 12 to 18 cts. The cost of application was about 2 cts. per gallon for 1/8-gal. applications. Covering material was variable in price, while the cost of applying the cover ranged from 1/2 to 1 ct. per square yard.

Bituminous Carpet.—A bituminous carpet is a bituminous surface 3/8 to 5/8 in. thick made by successive alternate applications of binder and aggregate united by rolling. In fact, it is essentially a double or triple surface treatment. Owing to the greater thickness, however, a somewhat stiffer binder than is used for surface treatments is preferable. Such binders are frequently termed *carpeting mediums.* They lie between the

TABLE 11-2.—GALLONS OF BINDER PER MILE FOR SURFACE APPLICATIONS

Gallons per square yard	Width treated, feet								
	20	18	16	14	12	11	10	9	8
1/8	1,468	1,320	1,173	1,027	880	807	734	660	586
1/7	1,676	1,509	1,341	1,173	1,006	922	838	754	670
1/6	1,956	1,760	1,564	1,369	1,173	1,076	978	880	782
2/10	2,347	2,112	1,877	1,643	1,408	1,291	1,173	1,056	938
1/4	2,933	2,640	2,347	2,053	1,760	1,613	1,467	1,320	1,173
3/10	3,520	3,168	2,816	2,464	2,112	1,936	1,760	1,584	1,408
1/3	3,910	3,520	3,129	2,738	2,346	2,151	1,955	1,760	1,564
4/10	4,692	4,224	3,754	3,285	2,816	2,581	2,346	2,112	1,877
1/2	5,866	5,280	4,693	4,107	3,520	3,227	2,933	2,640	2,347
3/4	8,802	7,920	7,041	6,159	5,280	4,839	4,401	3,960	3,520
1	11,734	10,560	9,387	8,213	7,040	6,454	5,867	5,280	4,693
1 1/4	14,670	13,200	11,735	10,265	8,800	8,065	7,335	6,600	5,868
1 1/2	17,604	15,840	14,082	12,318	10,560	9,678	8,802	7,920	7,041
1 3/4	20,538	18,480	16,429	14,371	12,320	11,293	10,269	9,240	8,214
2	23,468	21,120	18,774	16,426	14,080	12,908	11,734	10,560	9,387
2 1/4	26,400	23,760	21,120	18,480	15,840	14,521	13,200	11,880	10,560
2 1/2	29,334	26,400	23,470	20,533	17,600	16,133	14,667	13,200	11,735

bituminous cements and the liquid binders. They may be tar or asphalt and of either the hot- or cold-application type.

The process of construction is essentially the same as for surface treatments. After the surface is prepared, the first application of 0.4 to 0.5 gal. of binder per square yard is spread and covered with 20 to 25 lb. per square yard of stone chips or pea gravel and well rolled. After this layer has set, a second one is applied in the same way. This usually is enough but sometimes three applications are made, each one being somewhat lighter. The cost can be estimated in the same manner as surface treatments.

Carpets are used on gravel and macadam roads which have sufficient strength to support the loads but whose surfaces are unable to withstand the effect of traffic. They are sometimes applied to old concrete and brick pavements which are reasonably true to grade and crown but which have scaled or worn. A carpet is never a feature of new work.

Seal Coat.—A seal coat is a surface treatment applied to certain kinds of bituminous pavements as part of the process of construction. When the primary surface has reached a certain stage, the surface treatment is made exactly as previously described. The binder used is the same as that used in the main part of the surface and therefore seal coats are often applied hot. A *double seal coat* is merely a regular seal coat followed by a second one several weeks or more after the original construction. Surface treatments on old bituminous surfaces are sometimes called seal coats.

Skin Treatment.—This is a tar treatment for gravel roads which has given excellent results, especially in the New England states. The gravel is scarified and brought to proper shape. The excess dust or loose material is then swept off. About ⅙ gal. per square yard of light tar heated to about 60°C. is applied and permitted to penetrate for at least 2 days. A second application of about ⅓ gal. per square yard is then made and covered with sufficient coarse sand or pea gravel to prevent bleeding. Traffic soon irons out the surface until it has a surface much like tar macadam in appearance and antiskid characteristics. Such a treatment will last one to two seasons and at normal prices will cost 8 to 12 cts. per square yard.

MULCH TYPES

The mulch types are made by mixing a bituminous binder into the top inch or so of the existing surface and then spreading this loose "mulch" over the roadway where it is compacted by traffic aided by blading. In general, material in place is used for the aggregate but sometimes some new material is added. This process forms a dustless mat usually 1½ to 2 in. in thickness which takes the wear of traffic and protects the subgrade from water.

Wisconsin Treatment.—This treatment was devised by the Wisconsin Highway Commission to take care of some heavily traveled gravel roads and has given excellent results. The road

is scarified and brought to shape with some loose material on top. About ⅓ gal. per square yard of tar (Table 3-3) is spread as in the skin treatment. Immediately following this treatment, a blade grader is used to cut the surface about 1 in. deep and move the material to one side. A second application of tar of the same amount is made and the loose material moved back over it. Two or three additional movements are made to mix the tar and gravel thoroughly, after which the surface is brought to shape. Traffic is admitted at once and soon irons out the surface, sometimes aided by light blading. After traffic has used the road a

FIG. 11-2.—Wisconsin treatment of gravel.

few days, a light seal coat is applied if the surface shows a tendency to be loose or porous.

This method forms a mat 1½ to 2 in. thick which usually will last several seasons and can be kept in good condition during this time by an occasional light seal coat. The cost ranges from 15 to 25 cts. per square yard.

Asphalt Mulch.—This is essentially the same as the Wisconsin treatment except that asphaltic material is used in place of tar. Medium- to slow-curing liquid asphalts (Table 3-1) work well. Hot applications and emulsions cannot be used because they set too fast. Excellent results have been obtained at slightly less cost than the Wisconsin treatment since the asphalts are usually somewhat lower in price than the tars.

Oil-sand Mat.—This is a form of surfacing that has proved effective in some of the Great Plains states where the soil is essentially sand. Generally the sand on the road is used but sometimes additional sand of better quality is added. The surface is loosened for a depth of 2 to 3 in. and the bituminous material sprayed on a rate of about ½ gal. per square yard per inch of depth. This is immediately incorporated by discing and harrowing, after which the resulting "mulch" is spread by blades

and compacted by traffic. In some cases road oil having above 65 percent of 100 penetration residue has given good results. In other locations Mexican asphaltic oils have seemed to work better, while in other places good results have been obtained with cut-backs. The oil-sand mats show a wide range in kinds of binder used, adaptability to different sand soils, and methods of construction. The oiled earth road made by the mixing method is a close relative. The cost varies primarily with the kind and amount of oil used and can be closely estimated when the local prices are known. From $50 to $100 per mile for a double-lane width should be allowed for mixing and shaping.

PENETRATION TYPES

In the penetration types a layer of rather coarse aggregate is spread on the road and more or less compacted. The bituminous binder is then applied to the surface and worked into the mass of the aggregate for a limited depth.

Bituminous Macadam.—This is a wearing course composed of broken stone bound together with a bituminous binder which is applied to the surface and permitted to penetrate into the layer of stone. For this reason, it is frequently termed *penetration macadam.* The construction of a penetration macadam is exactly analogous to a waterbound macadam except for the kind of binder and the method of its application.

Base.—A penetration macadam surface is usually laid on a base course of ordinary waterbound macadam or as a resurfacing course on any type of existing pavement. Occasionally a concrete base is used; but if a concrete base is justifiable, so is a higher type of surface.

On new work, a waterbound macadam base is usually employed. It is laid exactly the same as if the surface were to be waterbound. If the pavement is to be more than 8 in. thick, the base should be made in two courses with or without stone dust binder as may seem necessary.

Surface.—Stone for the surface may be somewhat smaller than for waterbound macadam. Limestone should be 1½ to 2 in. in maximum size, while granite and trap may be 1 to 1½ in., both grading down to about ¾ in. The stone is spread and rolled with an 8- to 10-ton roller until it is well compacted and shows little displacement under the roller. The work should cease before the stones commence to crush.

The heated bituminous cement is then applied at a temperature of 100 to 125°C. for tar and 125 to 175°C. for asphalt and at the rate of about 1½ to 2½ gal. per square yard, depending on the gradation of the stone and the desired depth of penetration. Stone chips are then spread at the rate of about 1 cu. yd. to every 125 to 150 sq. yd. and the surface rolled with a 5- to 10-ton roller. Stone chips are added as required and spread with stiff brushes to cover spots where the binder shows through, or binder is supplied by hand if necessary where bare places show. The surface is rolled until practically cool. It should show a uniform surface of chips with the binder oozing through but without areas

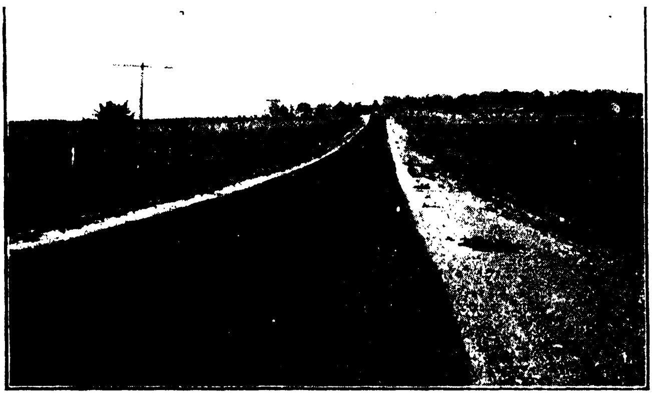


FIG. 11-3.—An excellent stretch of asphalt macadam.

showing either uncoated chips or free binder. The binder will ordinarily penetrate to a depth of 2 to 2½ in. A single roller can compact and finish about 600 to 800 sq. yd. per 8-hr. day.

Seal Coat.—A seal coat consisting of about ⅛ to ¼ gal. of binder per square yard, followed by stone chips and further rolling, is normally applied immediately. This serves to give a dense, smooth surface. Sometimes a second seal coat is applied, usually several months later, when imperfections have had an opportunity to show up and be remedied. This is termed *double seal coat* work and is to be recommended.

Characteristics.—A bituminous macadam surface is smooth, dustless, and resilient. After some wear the surface will show a mosaic of stone in bituminous binder. It gives good footing and traction when dry but tends to become slippery when wet. Under a fair volume of moderate-weight traffic, it will hold up well. It is not to be recommended on roads or streets carrying heavy

loads or a large volume of traffic. Neither is it desirable on roads with little traffic, since, in common with all bituminous surface, some traffic is necessary to keep the surface rolled down. The surface can be kept in good condition by occasional surface treatment.

Patching is done by cutting out the defect, replacing the base if necessary, then tamping in stone and applying binder by hand and compacting by rolling or tamping.

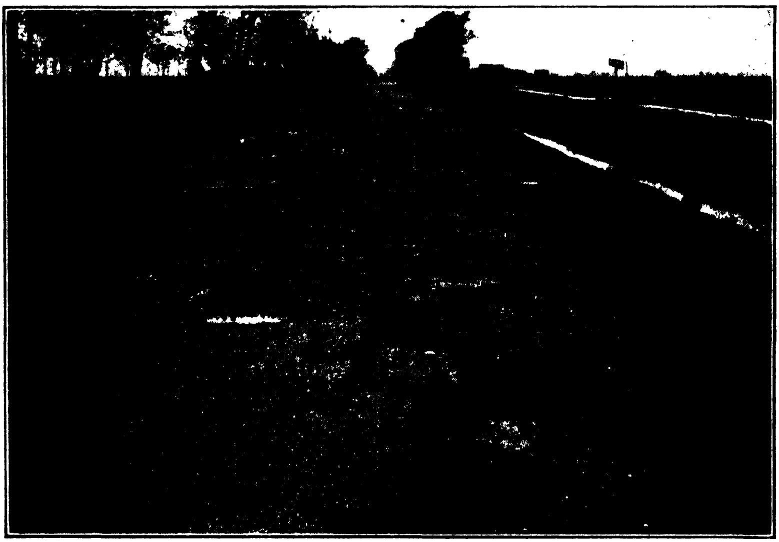


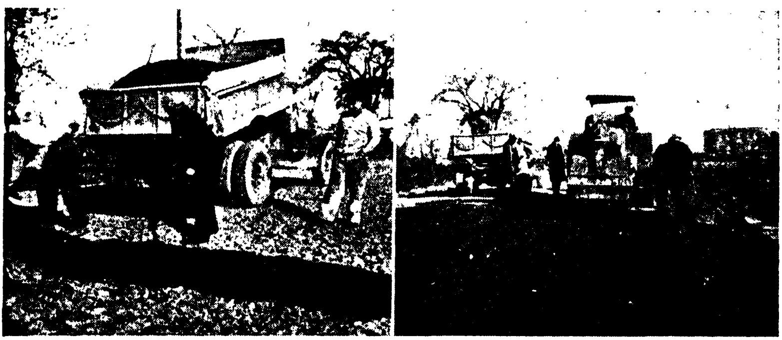
FIG. 11-4.—Asphalt macadam destroyed by excess traffic.

Cost.—The cost of penetration macadam varies with the prices of material and labor. For the same thickness, the amount of stone is the same as for waterbound macadam but the amount of screenings or chips is somewhat less. This is compensated, however, by somewhat more cost in distributing the chips on the penetration job. The total amount of rolling is about the same as for waterbound macadam. The principal difference in cost is therefore due to the binder.

Asphalt at $27 per ton is practically 12 cts. per gallon. To this must be added about 2 cts. for heating and applying which makes about 14 cts. per gallon. With a total of 2½ gal. per square yard, the cost of binder is about 35 cts. per square yard which may be added to the cost of waterbound macadam. Tar will usually be somewhat more than these figures.

With stone at $2 per ton on the road, waterbound macadam 8 in. thick will cost $1 to $1.25 per square yard with common labor at 40 cts. per hour and bituminous macadam $1.25 to $1.75, or about $6,500 to $8,000 per mile 18 ft. wide for the latter, exclusive of all grading and accessories.

Mastic Macadam.—This is a newcomer in the family of bituminous tops, having been introduced since 1930. So far tar has been used in its construction but there is no reason to suppose that asphalts will not be tried—or that they would not be satisfactory. All of the details have not as yet been perfected



A *B*

FIG. 11-5.—Mastic macadam. *A*, spreading the mastic on the rolled stone; *B*, rolling the surface.

but the essential features are as here given. A course of 2- to 2½-in. broken stone deep enough to support the loads is laid and partially compacted by rolling. Tar mastic consisting of sand with approximately 8 percent of bitumen is spread over the stone and rolled into it. Mastic is added as required until the stone has taken up all it will and a surface layer remains which is rolled firm. Sufficient data are not yet available (1935) as to cost, character, and life.

MIXED-IN-PLACE TYPES

The mixed-in-place types include those surfaces formed by spreading a coarse or graded aggregate on the subgrade, adding the necessary bituminous binder to the top, and mixing the two thoroughly together, after which the mixture is spread evenly and compacted. They merge into the mulch types, on the one hand, and approach the road-mixed types, on the other.

The mixed-in-place types are the direct outgrowth of the *tar retread* described below. So definite is this relationship that the term *retread* is often applied to any mixed-in-place surface, irrespective of whether it contains a tar or an asphalt binder.

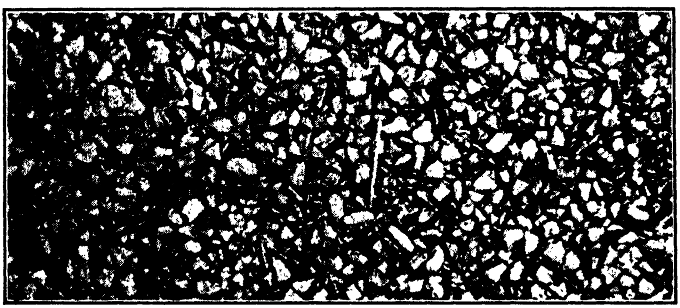
Tar Retread.—The tar retread was originally developed in Pennsylvania as a surfacing for shale, gravel, macadam, and similar roads, under moderate traffic. The existing surface is brought to as good condition as time, traffic, and available funds will permit, and the dust and dirt removed. It is desirable but not essential to give the subgrade a prime coat of $\frac{3}{8}$ to $\frac{1}{2}$ gal. per square yard of light tar and permit this to penetrate well. A layer of crushed stone ranging in size from $\frac{3}{4}$ to 1 in. but containing 10 to 15 percent of finer material is then spread to a depth of about 2 in. About $\frac{3}{4}$ gal. per square yard of retread tar (originally Tarvia *B*) is then applied to the stone. The aggregate and tar are then mixed by blading back and forth with a blade grader or with one of the special machines developed for this work. The mixture is then spread evenly and may be rolled. Traffic is admitted and the mixture bladed daily to prevent the formation of ruts until the tar has set, which requires 3 to 6 days. A seal coat using about $\frac{1}{4}$ gal. of binder and 15 lb. of stone chips per square yard and preferably at least lightly rolled should be added any time within 6 months.

This type of surface does not have sufficient load capacity to be used directly on an earth subgrade. For this reason a heavier form made in two stages has been developed. The earth road is prepared and primed as above indicated. A layer of stone up to $1\frac{1}{2}$-in. size and about 3 in. thick is then spread. About 1 gal. per square yard of tar is applied and the materials mixed as before. When this layer has consolidated, a second course essentially as above described is added including the seal coat. In this way a depth of about 5 in. can be obtained. It might be considered as a retread surface on a black base.

The cost of the simple retread 2 in. thick generally ranges from 30 to 40 cts. per square yard but may reach 50 cts. The 5-in. type has cost from 80 cts. to $1.10 per square yard.

Mixed-in-place Asphalt Surfaces.—The use of asphalt instead of tar followed rapidly on the introduction of the tar retread and its use has also been well developed. The process of construction with asphalt is practically the same as with tar, as described above. A slow- or medium-curing asphalt cutback or very slow-

A. The road just after applying the tar.



B. Looking down on the tarred stone.

C. The road after a few days of use.
FIG. 11-6.—Tar retread.

breaking emulsion may be used. The subgrade is primed with the same material as used in the surface mixture except in case of the heavy type applied to an earth road, when the best results are obtained by using a regular road oil adapted to earth road oiling. The cost is likely to be somewhat less than with tar when a cut-back is used and about the same when an emulsion is used.

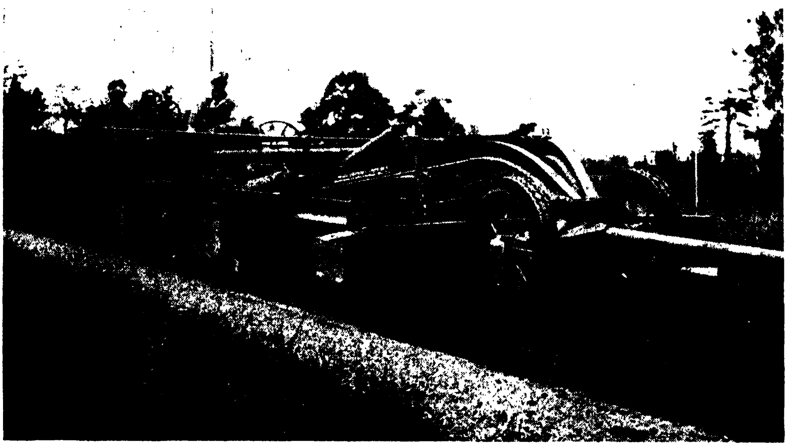


FIG. 11-7.—A special blade machine for mixed-in-place bituminous surfaces.

ROAD-MIXED TYPES

This group of surfaces includes those made by distributing the desired aggregate along the roadway, from which it is picked by a special mixer, mixed with the bituminous binder, and redeposited on the road where it is spread and compacted. These types occupy a position between the mixed-in-place types just described and the plant mixes described later.

Asphalt Mixtures.—These range all the way from oil-sand mats (mastic or sheet asphalt type of mixture) to practically a Bitulithic type of mixture. The aggregate is distributed along the roadway, generally in a windrow. If possible, a suitable gradation is obtained at the plant. If not, two or more aggregates are mixed on the road, generally by blading. Sometimes the size of windrow is judged by eye and trucks kept at hand to take up an excess or supply a deficiency in amount. Often a

special form of template is used which cuts the windrow to a uniform cross-section of the right size to supply the correct amount of aggregate. Several types of machines are on the market. All of these have provision for picking up the aggregate, adding to it the correct amount of bitumen, mixing the two together, and depositing the mixture on the road. Machines have also been developed for spreading and compacting the mixture. A seal coat may or may not be applied, depending on the type of mixture.

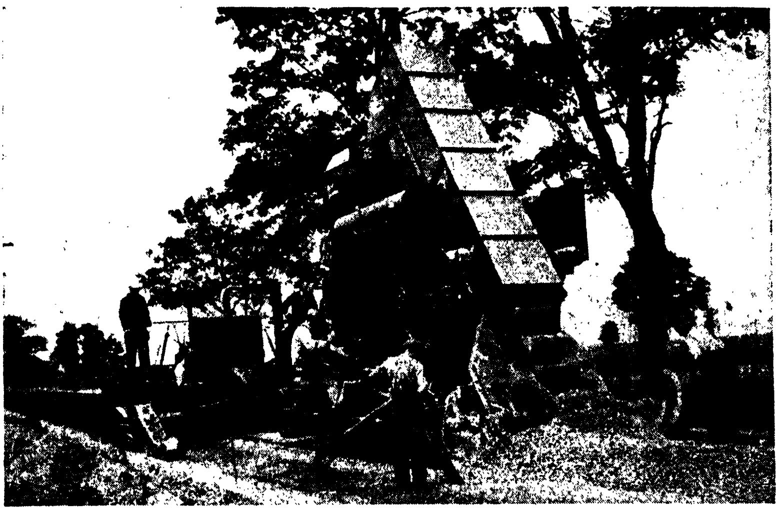


FIG. 11-8.—One type of road-mix machine combined with a spreader and tamper.

Hot mixes, cutbacks, and emulsions are used. The gradation of the aggregates and the amounts of asphalt cement are essentially the same as given later for the plant-mixed types. In fact the road mixes are essentially the same as the plant mixes except for somewhat less refinement in the proportioning and for the fact that they are mixed in a mixer moving on the road instead of at a central plant.

The road-mixed types are, in general, somewhat lower in cost of construction than the corresponding plant mixes.

Tar Mixtures.—Tar may be used as the binder in any of the mixtures adapted to the road-mix process. In general, however, the use of tar is restricted to types having a coarse ungraded aggregate and hence resemble the mixture obtained in the tar retread.

PLANT-MIXED TYPES

SHEET ASPHALT

A sheet asphalt pavement is one having a wearing surface consisting of an asphalt mortar composed of fine mineral aggregate and asphalt cement. The complete pavement consists of a *base*, usually portland-cement concrete, a *binder course* of asphalt concrete, and the *top* or wearing surface of asphalt mortar.

Base.—On entirely new work, a concrete base is universally used. The proportions are usually 1:2½:5 to 1:3:6 with a thickness of 5 to 8 in., the normal thickness being 6 in. Occasionally richer mixes up to 1:2:3 are used if greater strength is desired. Usually, the question of cost has been the governing factor in thickness but from a truly economic standpoint the base should be designed for the given conditions as outlined in Chap. 9.

The concrete base is finished with a roughened surface so that the asphaltic surface will adhere to it. The perforated roller described in Chap. 9 does this well with concrete of the proper consistency. Otherwise the surface is roughened with rakes or picks just prior to setting. Worn brick, stone block, and concrete pavements are frequently used as bases for sheet asphalt. They make good bases, if structurally strong enough and if care is taken to repair them properly and to clean them thoroughly. Gravel, macadam, and black base are very rarely used and are not recommended. A good surface deserves an adequate base.

Binder Course.—The function of the binder course is to furnish a bond between the surface and the base and to take up irregularities of the base. Experience has shown that when the wearing surface is placed directly on the base there is considerable tendency for it to creep and become rough. The binder course consists of a layer of asphalt concrete designed to overcome this difficulty. For light- and medium-traffic roads and streets, a thickness of 1 in. is often used but for heavy traffic 1½ in. is better.

Open binder is composed of stone ranging from about ½ to 1 in. in size, mixed with 5 to 8 percent of asphalt cement of the same grade used in the top. The amount of asphalt cement is just enough to cover all the particles of stone but not to fill the voids. No attempt is made to secure a dense mix. In fact, the

intention is to produce a binder course with an open, porous surface. The material of the wearing course enters into the porous surface and bonds well with it. The open binder, on account of its open structure, develops only moderate bond with the base and not being well graded possesses only moderate stability. It is, therefore, suitable only for the thinner courses and pavements carrying moderate traffic.

Close binder is composed of a better graded aggregate so as to secure a denser mixture with a less open surface. The aggregate consists of sand and stone graded up to 1-in. size in such proportions that 25 to 35 percent passes a 10-mesh sieve. The amount of asphalt cement ranges from 7 to 9 percent by weight. The close binder bonds well with the base, possesses high stability, and unites firmly with the wearing surface. It is suitable, therefore, for use in thicker courses under heavy traffic. This type of binder on account of its greater stability should be used for filling holes and depressions in existing pavement when being resurfaced with sheet asphalt.

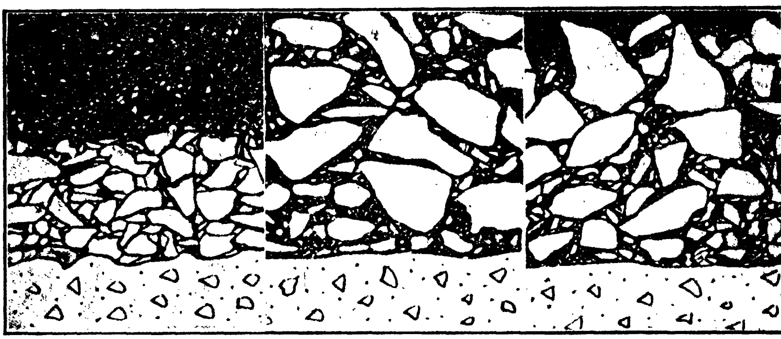
Old surface mixtures are sometimes melted and mixed with sufficient asphalt cement and graded stone to give a close binder. If reasonably clean, carefully broken up, and melted, and then properly mixed with new materials, good results can be obtained with some economy.

Wearing Surface.—The wearing surface is an asphalt mastic or mortar composed of sand, filler, and asphalt cement. The sand forms the body of the mixture and experience has demonstrated that the stability of the surface depends a great deal on the gradation of the sand. For this purpose the maximum size of grain generally specified is that passing a 10-mesh sieve or about 1/16 in. There appears, however, to be no real evidence that larger grains, perhaps up to 1/4 in., would be objectionable, especially with a properly proportioned amount of filler.

Filler.—The filler is that portion of the mineral aggregate which passes a 200-mesh sieve. Finely ground limestone or portland cement is most commonly used. The former is somewhat less expensive, while the latter is considered somewhat the better. Silica dust, pulverized clay, and hydrated lime are also used. The last seems to possess excellent qualities and its price is low. The filler apparently fills the minute voids and therefore adds density to the mixture. It appears to mix directly with the asphalt cement, adding stability to it with-

out sacrificing cementing qualities. The filler, therefore, should not only pass a 200-mesh sieve but should contain considerable amounts of much finer material.

Commercial fillers generally do not all pass a 200-mesh, and therefore, in computing the amount to use, allowance should be made for this fact. For example, the average portland cement is only about 85 percent finer than 200-mesh. The other 15 percent should therefore be included in the sand. Similarly, if material passing 200-mesh is found in the sand, it should be considered as filler and allowed for in computing the amount of filler.



Sheet asphalt Asphalt concrete Warrenite-bitulithic

FIG. 11-9.—Cross sections of bituminous pavements.

Proportions.—Experience has shown that some variation is permissible in the proportion of asphalt cement, filler, and aggregate and in the gradation of the latter. Table 11-3 gives the average proportions. In general, more variation is permissible in the material larger than the No. 40 or 48 sieve than in that smaller, except the filler. Experiments indicate that higher penetration asphalt cements may be used and their consistency controlled by the amount of filler. In fact the stability seems to be improved by using somewhat softer asphalt cements with increased amounts of filler up to about 20 percent. At the same time the tendency to become brittle in cold weather is reduced.

Asphalt Cement.—The asphalt cement may be either a native or an artificial asphalt. Trinidad Lake asphalt is a popular variety of native material. An asphalt of high stability having a penetration of 40 to 60 is commonly used in temperate climates. In the northern states, the penetration may be 10 points higher

and in the southern states 5 to 10 points lower. As indicated above, the trend seems to be toward softer asphalt cements stabilized by an increased amount of filler.

TABLE 11-3.—APPROXIMATE NORMAL COMPOSITION OF SHEET ASPHALT

Gradation of aggregate, Total percents by weight passing					
U. S. Standard sieves			Tyler standard sieves		
Sieve number	Heavy traffic	Light traffic	Sieve number	Heavy traffic	Light traffic
10 (0.062 in.)	100	100	8 (0.092 in.)	100	100
20	96	93	14	97	94
30	91	85	28	91	84
40	82	73			
50	71	60	48	70	60
80	43	31			
100	30	21	100	29	21
200 (filler)	15	11	200 (filler)	15	11
Proportion by weight, percents					
Aggregate.....	89.5	90.0	Aggregate.....	89.5	90.0
Bitumen	10.5	10.0	Bitumen......	10.5	10.0

Quantities and Weight.—Specifications fix the proportions by weight. If the asphalt cement is 100 percent bitumen, if the material used for filler all passes the 200-mesh, and if the sand is all retained on the 200-mesh, then the percentages shown in the specifications will be used directly. Frequently, the materials do not have these characteristics so that an adjustment of quantities should be made. Of course, this needs to be done only when the variation of the composition of the materials is large.

Example.—Assume that the specifications call for a mix of 10 parts bitumen, 15 parts filler, and 75 parts sand. Assume also that the asphalt cement contains only 90 percent bitumen, the stone dust used for filler has 90 percent passing the 200 mesh, while all of the sand is retained on the 200 mesh. The amount of asphalt cement required is now $\frac{10.0}{0.9} = 11.1$ parts, of which 1.1 parts may be considered as filler. The amount of dust is $\frac{15.0 - 1.1}{0.9} = 15.5$ parts, of which 15.5 − 13.9 or 1.6 parts are sand. The amount of sand then is 75.0 − 1.6 = 73.4 parts. Thus a 1,000-lb. batch would consist of 111 lb. of asphalt, 155 lb. of stone dust, and 734 lb. of sand.

A wearing surface 1½ in. thick will require approximately 14 lb. of oil asphalt cement, 22 lb. of filler, and 110 lb. of sand per square yard. Close binder 1 in. thick will add about 8 lb. of asphalt cement, 5 lb. of filler, 30 lb. of sand, and 60 lb. of stone per square yard. These quantities are sufficiently accurate for ordinary estimates of total materials required. From these figures the total weight of the sheet asphalt surface, including top and binder, 2½ in. thick is 249 lb. per square yard or practically 100 lb. per square yard per inch of thickness.

Sheet asphalt Asphalt concrete

FIG. 11-10.—Laying sheet asphalt and asphalt concrete.

Construction.—The asphalt is heated in suitable tanks, either by direct fire or by steam coils. Wood, coal, or oil fuel is used. The asphalt is stirred by air or steam jets or with mechanical stirrers. It is heated to about 150°C. for the binder and 175°C. for the top. Stirring with steam may introduce a little water into the mixture, while air stirring may give some of the effects of blowing the asphalt, especially if the material is heated very hot.

The sand is heated in a rotary drum to a temperature approximately the same as the asphalt. Care must be taken not to overheat the sand as it may then burn the asphalt in contact with the grains and reduce the adhesion. The filler material is usually added cold as it is dry and the amount is not sufficient to lower the temperature.

Both binder and top are mixed in a double pug-mill type of mixer, dumping through the bottom. This type of mixer is desirable as it can be kept reasonably clean, the mixing is visible, and the materials are easily put into it. The asphalt cement, sand, and filler are weighed on suitable scales and run into the mixer and mixed thoroughly. Complete mixing is indicated by

uniform color and consistency and requires from 1 to 2 min. The mixer is usually so set as to dump directly into the wagons or trucks used for hauling. The mixture is covered with canvas and hauled to the job. It should reach the work at a temperature between 135 and 150°C. for binder and 160 and 175°C. for top.

The material is dumped in piles in such positions that the entire pile must be shoveled into place. It is spread to uniform thickness by means of heavy straight tooth rakes. Occasionally a template is used for checking the surface, but usually the spreading is simply done by eye. The more accurate the surface of the base, the easier it is to spread the mixture to proper shape.

As soon as the binder is placed it is rolled. A 2- to 4-ton tandem roller is first used until the binder course is capable of supporting a heavier roller without shoving up in front of it. An 8- or 10-ton roller is then used until the course is thoroughly compacted. Frequently a three-wheel roller weighing 8 to 10 tons is used without the light roller. After the first passage of the roller the surface of the binder should be checked with a 10-ft. straightedge and any marked irregularities corrected.

The top should be placed as soon as possible after the binder is rolled, preferably before it has entirely cooled. The top is mixed, hauled, dumped, spread, and rolled the same as the binder. After the first passage of the roller the surface should be checked with a 10-ft. straightedge. Any irregularities should be corrected and the surface again checked while the rolling proceeds. A well-built surface should not have a variation of over 1/8 in. in 10 ft. Where impossible to roll either the binder or top, as around manholes, inlets, etc., it is tamped and smoothed with heated metal tampers and smoothing irons. Usually a light coating of portland cement or stone dust is swept over the surface just prior to the final rolling. It is claimed that it seals the surface, making it denser, but this is not an established fact. It does, however, add a finished appearance to the job. The pavement is ready for traffic as soon as it cools to air temperature. Not less than 24 hr. should be allowed for this purpose.

A pair of rollers with one operator can compact and finish 600 to 800 sq. yd. per 8-hr. day. With a second operator, so that both machines are kept busy, 800 to 1,000 sq. yd. can be covered in the same time.

Machines similar to the finishing machines used on concrete pavements have been introduced since 1930 for shaping and compacting bituminous surfaces. While they have not as yet (1935) come into general use, they appear to have merit and the future may see considerable development of such equipment.

Characteristics.—A well-laid sheet asphalt pavement is smooth, dustless, elastic, resilient, and easily cleaned. It gives good foothold and traction but tends to become slippery when wet. It is a renewable surface pavement. Thus, if an adequate foundation is provided, the surface can be economically renewed from time to time as it wears out, at a minimum cost. Sheet asphalt is adaptable to roadways carrying a considerable volume of fast-moving, moderate-weight vehicles which spread over the surface, *i.e.*, do not run in lanes. On account of its color it absorbs heat, has low visibility, and is perhaps not so pleasing in appearance as some other types.

Failures.—The principal causes of failure are too much bitumen which causes the pavement to be plastic and easily displaced; similar action due to too soft an asphalt cement; too little or too hard an asphalt cement which causes the surface to crack and break up; poor or overheated asphalt; poorly graded aggregate, imperfect mixing, inadequate rolling, etc. Poor gradation of aggregate or insufficient filler is especially likely to cause lack of stability under load. Concentration of traffic into lanes is certain to cause trouble sooner or later. The plasticity, which is one of the principal advantages of an asphaltic surface, becomes its weakness under such traffic.

Modification.—Sheet asphalt is modified by the addition of 25 percent or less of stone chips passing ½ screen. This is frequently termed *topeka mix* or *stone-filled sheet asphalt.* It is the outgrowth of a mixture containing not more than 10 percent of stone chips used in Topeka, Kan., and which a federal court ruled did not infringe the Bitulithic patents.

Willite is a sheet asphalt, the essential point being the addition of a certain percentage of copper sulphate to the asphalt cement. It is claimed that this gives additional toughness to the mixture. At first, aggregates for Willite were chosen with little care, local materials of nearly any character being used, but now selected aggregates are employed the same as for sheet asphalt.

Cost.—The cost of sheet asphalt pavement shows quite a wide range of variation depending on proximity of materials, labor costs, and the magnitude of the work.

The cost is also affected by the use of the so-called open or closed specifications. *Closed specifications* limit the asphalt cement to a single specified variety, while *open specifications* permit the use of any kind, native or artificial, which meets fixed requirements. Usually, open specifications are made to cover each kind of asphalt and the bidders are required to designate the particular variety included in each bid. In general, open specifications have resulted in lower prices, even on exactly identical mixtures.

The cost of sheet asphalt surface, exclusive of the base and all excavation and accessories, etc., for a total thickness of 2½ in. may be roughly itemized as follows:

Aggregates	$0.35 per square yard
Asphalt cement	0.35 per square yard
Plant labor	0.20 per square yard
Street labor	0.20 per square yard
Overhead and profit	0.60 per square yard
Total	1.70 per square yard

The foregoing total corresponds closely to the average bid prices in the Middle West in 1934 and amounts to about 65 cts. per square yard per inch of thickness.

PLANT-MIXED TYPES

BITUMINOUS CONCRETE

Bituminous concrete is a pavement mixture composed of a coarse mineral aggregate cemented together with a bituminous cement, the materials being mixed together before placing in the roadway. It is exactly analogous to portland-cement concrete in composition but differs from it in proportioning, mixing, placing, and setting, on account of the difference in the characteristics of the binder.

Owing to the viscous, adhesive character of the binder, a bituminous concrete is plastic instead of rigid. An excess of binder does not increase the strength but tends to reduce the stability of the pavement by developing undue plasticity. Bituminous concrete may be considered as sheet asphalt to which has been added coarse aggregate. The mortar portion in dense bituminous concrete is governed practically by the same factors as is the sheet asphalt mixture.

Sometimes a bituminous concrete made with ungraded stone, or with stone screened to nearly one size like macadam stone, is termed *mixed macadam*, but the term is a misnomer. The point of distinction between bituminous concrete and bituminous macadam is that the materials in the former are mixed together and then placed like portland-cement concrete, while in the latter the stone is placed and rolled the same as for waterbound macadam and then a bituminous binder applied from the top.

Base.—Bituminous concrete may be laid on any type of base. It is frequently used as a resurfacing material on gravel, macadam, concrete, stone block, or brick. New work is occasionally laid on macadam but concrete is more common and much superior. Black base is sometimes employed. Whatever the type of base, it must be properly designed for the particular location and loads. Gravel, macadam, and black base should be not less than 8 in. thick. Concrete should be not less than 6 in. thick, using a 1:3:5 mix (see Chap. 9).

Bituminous Cement.—The bituminous cement may be either tar or asphalt but asphalt predominates. Hot-mix types, cutbacks, and emulsions are all used. For hot mixes the penetration of the asphalt cements may range from about 50 for natural asphalts to 100 for oil asphalts. Emulsions and cutbacks may be made from oil asphalts with penetrations up to 120. As with sheet asphalt there is a relation between the amount of filler and the consistency of the cement so that softer materials can be used by increasing the filler. Open and closed specifications may appear, especially with hot mixes, with the same results as with sheet asphalt. (See Tables 3-1, 3-2, and 3-3.)

Aggregate.—The mineral aggregate used in bituminous concrete ranges in size from dust to a maximum of about 1¼ in. Gravel is sometimes used as coarse aggregate but crushed stone is more common and is generally preferred. Investigations, however, indicate that, when the mixture is properly proportioned, gravel is entirely satisfactory. The fine aggregate is almost invariably natural sand. Filler is that portion of the mineral material passing a 200-mesh sieve, as in sheet asphalt. It adds density to the mixture and plays an important part in the behavior of the surface. The amount of filler should bear about the same relation to the amount of asphalt as in sheet asphalt (see Table 11-3).

Types of Bituminous Concrete.—Several types of bituminous concrete are recognized, based on the character of the coarse aggregate.

Ungraded aggregate mixtures are made of *crusher-run stone* or stone screened to essentially *one size* and these last names are frequently applied to the two types, respectively. Proper adjustment of the crusher may yield a crusher-run product approximating the coarse-graded or Bitulithic aggregate given below. One-size stone always yields an open, porous mixture. Ungraded aggregates are used for sheet asphalt binder courses, black bases, and sometimes road surfaces. When used for road surfacing, they should be finished with a seal coat. When coarse one-size stone is used, it is occasionally but improperly termed *mixed macadam*.

Fine-graded aggregate mixtures are graded aggregates up to ½ in. in size. These constitute the so-called *topeka* or *modified topeka* mixtures, sometimes referred to as *stone-filled sheet asphalt*. These surfaces are finished without a seal coat in the same manner as sheet asphalt.

Coarse-graded aggregate mixtures are sand, filler, and graded stone up to about 1¼-in. size. The materials are well graded for high density. These mixtures are used primarily as pavement surface, close binder in sheet asphalt, or black base. They were originally finished with a seal but this is now often omitted to improve the antiskid characteristics. Furthermore, since the expiration of the Bitulithic patents, there seems to be some tendency toward using a thin mastic coat to finish the surface.

TABLE 11-4.—APPROXIMATE COMPOSITION OF BITUMINOUS CONCRETE

U. S. Standard sieves		Percents by weight	
Passing	Retained	Fine-graded type	Coarse-graded type
1¼ in.	½ in.	. . . .	30 to 50
½ in.	4	12 to 25	15 to 25
4	10	7 to 20	4 to 15
10	40	10 to 26	
40	80	11 to 36	20 to 35
80	200	10 to 25	
200	. . . .	7 to 11	4 to 6
Bitumen		7½ to 9½	5 to 8

Warrenite-Bitulithic, the patents on which have now expired, consists of a layer 1½ to 2 in. thick of Bitulithic concrete covered with about ½ in. of rich mastic. (See Fig. 11-9.) The Bitulithic concrete is a coarse-graded asphalt concrete with the aggregate graded in accordance with limits fixed in the original patents and intended to secure the maximum density and stability in the aggregate itself. The two layers are laid loose and compacted together, which was a feature of the patents, and finished the same as sheet asphalt.

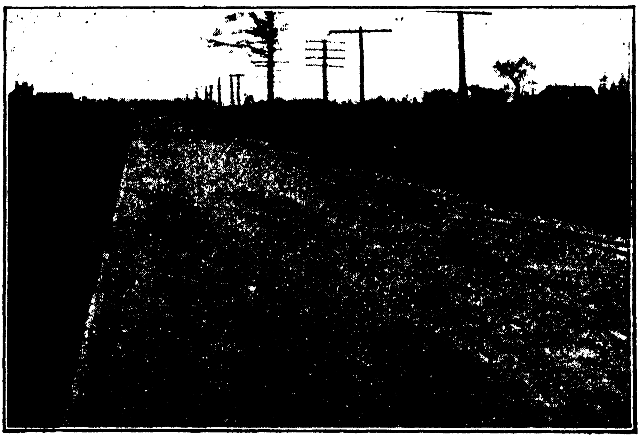


FIG. 11-11.—Asphalt concrete in distress. Located on a heavily traveled road where the traffic runs in definite lanes much of the time.

Construction.—The heating, measuring, mixing, placing, and compacting of bituminous concretes are performed in the same way and with the same equipment as for sheet asphalt. If a seal coat is used, it is applied in the manner previously described in this chapter. If a mastic top is used, as in the Warrenite-Bitulithic type, the coarse-graded concrete is placed and rolled once. The mastic is then spread and the whole compacted by further rolling.

Characteristics.—There is little difference in the general characteristics of bituminous concrete from sheet asphalt or, indeed, any of the bituminous surfaces. Specifically, the concrete differs somewhat in its behavior under traffic owing to the coarse aggregate. The principal sources of trouble are due to either too much asphalt cement or a material of too-high penetration, both of which result in creeping and the development of ruts and waves.

Thickness.—Bituminous concrete is usually made 2 or 2½ in. thick, rarely as much as 3 in. or as little as 1½ in. Experience seems to indicate that a minimum of 1½ in. is required for stability, and if cost prohibits this thickness it is more economical to reduce the surface to a simple carpet than to attempt to build and maintain a 1- to 1½-in. surface. A greater thickness than 2½ in. does not seem necessary for stability and reasonable life.

Cost.—Bituminous concrete can be built for less than sheet asphalt for exactly the same reason that portland-cement concrete can be made cheaper than the same volume of mortar of the same strength; *i.e.*, aggregate is cheaper than binder and the total amount of bitumen in the bituminous concrete is less than in sheet asphalt. Furthermore, the output in square yards from a given plant is higher on account of the smaller thickness and the one-course work, which results in lower mixing, placing, and operating costs.

The use of open or closed specifications also affects the price of bituminous concrete. A 2-in. surface at 1934 prices should cost on the average about $1.40 exclusive of base.

Variations.—*Amiesite* is an asphalt concrete which is shipped cold, spread on the base, and thoroughly rolled. It is especially suitable for small or isolated jobs where plant charges would be excessive. Its general characteristics and cost are about the same as other bituminous concrete. Its characteristic features are the treating of the aggregate with a "liquifier" to cut back the asphalt and cause it to adhere to the aggregate, and the addition of ½ to 1 percent of hydrated lime to the mixture after it is partially mixed. The original patents have expired.

Asphalt blocks are made of a well-graded asphalt concrete molded under heavy pressure. The surface size is about 6 by 12 in. and thicknesses of 1, 1½, 2, and 2½ in. are made. The general features of laying are described in Chap. 10.

Precote is a form of asphalt concrete using an emulsion. The emulsion is prepared on the job and the aggregate is coated by being immersed in the emulsion. It usually consists of a layer using aggregate up to about 1¼ in. and topped with a thinner layer in which clean chips up to about ½ in. are used.

The *Colprovia* process is one making use of powdered asphalt. Almost any grading of aggregate from sheet asphalt to one-size stone may be used as desired. The aggregate is mixed with powdered asphalt and an asphaltic oil in such proportions that

when the oil has fluxed the hard powdered asphalt there will result an asphalt cement of about normal consistency. This fluxing takes place gradually and the material is handled cold during the earlier part of this period.

There are numerous varieties of all these types. Some of them are marketed under trade names, while others are merely modifications resulting from certain conditions or available materials.

Maintenance.—The maintenance of bituminous surfaces naturally presents an extremely wide range of processes on account of the large variety of bituminous materials and numerous forms of construction. No definite rules and no typical prices can, therefore, be given.

In general, surface treatments, carpets, etc., are maintenance operations within themselves. Occasionally they may be patched, over limited areas, in much the same way as they were originally made. Those types of surfaces that have appreciable thickness and a definite composition are usually repaired by cutting out the defect and replacing it with a mixture similar to the original one although often hand mixed and placed. Such surfaces also receive surface treatments as a matter of maintenance. Proper and timely maintenance is essential to the success of bituminous surfaces.

Using Bituminous Materials.—The successful use of bituminous materials requires a knowledge of their characteristics and behavior and also intelligent supervision in the design and preparation of the mixtures.

Hot-mix cements must be heated carefully to a temperature just sufficient to give the required fluidity and should be kept at this temperature no longer than necessary. Otherwise the cement is likely to be damaged by driving off lighter constituents or modifying others present so that the cement in the final mixture is different from what it was at first. Hot-mix cements cannot be used with wet or cold aggregates. Moisture causes bubbling and prevents the binder from coating the aggregate. Cold aggregate chills the cement so that the mixture hardens before it can be placed. The aggregates should be dried and heated to about the same temperature as the cement. The only exception to this is the case of hot surface treatments or carpets. A hot mix is ready for traffic as soon as it cools to air temperatures which is one of the advantages of this kind of material.

Cutbacks do not require that the aggregates be heated or dried. They will not work with aggregates showing free water but surface-dry particles will be readily coated. Dust interferes very little with the coating of the aggregate, since the solvent in the cutback seems to penetrate it. In cool weather cutbacks work better if slightly warmed to give greater fluidity. This must be done carefully, and an open flame should not be used because of the low flash and fire points. A maximum of about 55°C. is as hot as they can be safely heated. Greater fluidity can also be obtained by thoroughly mixing in a small amount of light solvent such as gasoline, naphtha, or benzol. Allowance should be made for this addition in the total amount of cutback used.

Emulsions require careful selection and proper handling. They are not all alike and no one emulsion will work under all conditions. Much is still to be learned about them. Emulsions will not coat dusty stone, which seems to be largely a matter of surface tension. At the same time some emulsions will not coat certain aggregates even when clean, which is believed to be an effect of ionization. By modifying the emulsion, however, a form can be found which will work with such aggregates. The readiness with which an emulsion will coat a stone depends to a considerable degree on its own fluidity and the wetness of the stone. With wet stone an emulsion with less water may be desirable. The same material with dry stone may work better if water is added. The total amount of bitumen in the mix should be fixed and some leeway provided for changing the water content in the emulsion as actually used.

Road oils are generally easy to handle. Most of them require warming in cool weather. In general, their behavior is similar to that of cutbacks, but not being so cementitious they should not be used where high binding power is desired.

Tests.—Aside from the tests on the individual materials the mixtures themselves are often subjected to certain tests in the design or control of their composition.

The *pat test* was formerly much used in sheet asphalt work. A sufficient quantity of the hot mix is placed between sheets of wrapping paper and molded into a pat about 4 in. in diameter and ½ in. thick by striking with a block of wood. The character and density of the stain on the paper indicate the richness and uniformity of the mix.

The *extraction test* is used to determine the amount of bitumen in the mix. It is made by dissolving the bitumen, usually with carbon-disulphide, and separating it from the aggregate. Several different methods are used. For pavement mixtures one of the most common methods is with the New York hot extractor (A.S.T.M. D147-27). In place of this the *Rotarex* or centrifugal extractor may be used. (*U.S. Dept. Agr. Bull.* 1216.) For such materials as premolded expansion joints the Soxhlet extractor is suitable (*Bull.* 1216). These methods make it possible to determine the amount of bitumen actually in the mixture, and also to recover the bitumen and study its character.

One of the most important tests but one which, as yet, has not been standardized is that for *stability*, or the ability to withstand displacement under load. This test has taken different forms with different investigators. The methods include the deformation of specimen under compression, the penetration of a plunger into the mass, the forcing of an enclosed specimen through an opening, and the behavior of a specimen under shear. Temperature plays an important part in all bituminous tests and hence must be kept constant throughout a given test and also any series in which comparisons are to be made.

The *emulsification* test is sometimes used to determine the fitness of fine aggregates for use with road oils. Ten grams of fines passing the 200-mesh sieve and 50 cc. of heavy road oil warmed to about 55°C. are vigorously mixed for 5 min., after which 100 cc. of water at the same temperature is added and the stirring continued for another 5 min. Unsatisfactory fines will separate and settle to the bottom.

The *swell test* indicates the *soundness* of the mixture or its resistance to damage by infiltering water. A specimen about 4 in. in diameter and 4 in. thick is molded under pressure in a suitable form. The sample and container are then immersed in water and an Ames dial arranged to measure any increase in the thickness of the specimen. A swell of only 0.03 in. casts suspicion on the mixture, while a swell of 0.05 in. or more indicates an unstable mixture. The action is attributed to a preferential adsorption of water as compared with oil by certain aggregates. The water apparently displaces or disrupts the bitumen in contact with the aggregate and thus causes the mixture to disintegrate.

Low-cost Roads.—A great deal of attention is now being centered on so-called low-cost roads which are mostly of bitumi-

nous types since these are dustless and highly waterproof. The problem, however, is highly elusive and often deceiving. First of all, the term *low cost* is purely relative. For example, one state engineer indicated that a two-lane low-cost road should not exceed $6,000 per mile, while in another state the limit was set at $2,000 per mile. Furthermore, a certain type of road may be built for a certain sum in one locality but would cost several times as much in another. In one case it might be low cost and not in the other. It may happen also that a certain type has been successful in one location and thus results in low cost but becomes a total failure and hence expensive on a different soil or under different traffic. One of the most common methods of wasting money and ruining the reputation of a really excellent material is to attempt to use it under conditions to which it is not suited. Another interesting point is that, no sooner does an apparently low-cost product prove its worth under given conditions, than some one attempts to use it elsewhere, and in attempting to make it fit his conditions he begins to modify it, until it finally grows out of the low-cost class into the high type. In fact it is quite probable that all of the high types have resulted from trying to correct the inadequacies of a material subjected to conditions to which it was not suited. The field of low-cost bituminous roads offers enormous possibilities but success will be had only when and if a very considerable amount of "gray matter" is used in the process.

Problems

11-1. Make a bill of materials for 5 miles of asphalt macadam with double seal coat, 20 ft. wide and 8 in. thick with base unfilled.

11-2. How much stone and tar are required for a 2-in. retread with primer coat on 5 miles of sand-clay?

11-3. Make a bill of materials for 20,000 sq. yd. of sheet asphalt pavement with 1-in. close binder course and 1½-in. top, using the heavy traffic proportions in Table 11-3.

11-4. Substitute a 2½-in. coarse-graded asphalt concrete from Table 11-4 in the preceding problem.

11-5. A sheet asphalt top mixture is to contain 11 percent bitumen, 18 percent filler, and 71 percent sand, by weight. The asphalt cement is 88 percent bitumen, the filler material has 85 percent passing the 200 mesh, while 93 percent of the sand is retained on the 200 mesh. Compute the quantities for a 1000 lb. batch.

CHAPTER 12

ACCESSORIES

GUTTERS

A gutter is a shallow, artificially lined waterway, usually parallel with the roadway, for collecting and carrying surface water. It is analogous to the side ditch but differs from the ditch in that it is always lined, whereas the ditch is not. A gutter may be a separate structure, or it may be formed by the curb and the slope of the pavement surface.

Paved Gutter.—A paved gutter has a lining of separate pieces such as cobblestones, stone blocks, flagstone, or brick. Paved gutters are used on rural roads, drives in parks and estates, on unpaved streets, and in conjunction with gravel, macadam, and bituminous surfaces which easily erode, or which disintegrate when used as a gutter surfacing.

Cobblestone lining is frequently used where suitable stones are available, especially on park and private drives on account of its artistic appearance. It is unsuited to city conditions as the gutters are unsanitary and hard to clean. Flagstones, stone blocks, and brick are used for all classes of work, depending on the relative cost of the different materials. All form satisfactory gutters, when well laid. Ordinarily the lining is laid directly on the ground without a subbase.

Concrete Gutter.—Concrete gutters are reasonable in cost, easy to lay to line and grade, and can be given any desired shape. They are smooth, of good appearance, and easily cleaned. For these reasons the concrete gutter is largely displacing other types. The flat slab is used in conjunction with a plain concrete or stone curb. The *shallow V-type* is used where it is necessary to drive across the gutter as at private drives, alleys, etc. The *deep V-type* is used on rural roads. It is not an economical section because it is rather difficult to build and does not have water capacity in proportion to the amount of concrete used. When placed along the edge of the pavement slab it acts somewhat as a curb in preventing wheels from leaving the pavement but its

depth gives a sense of insecurity to the driver which results in traffic crowding toward the center, thus decreasing the effective width of pavement instead of adding to it as a gutter should. The *combined curb-and-gutter* is one of the best types and is very popular on city streets. It is less used on rural roads but its many advantages will doubtless increase its use thereon in the future. It is easy to build, forms a distinct margin to the roadway, adds to the effective width, and has adequate capacity.

The proportions for a concrete gutter should be the same as for concrete pavement, usually 1:2:3 or 1:2:3½. Flat or shallow gutters may be laid in one course and finished with float or trowel. The deep V-type and the combined curb-and-gutter are best made with a stiff concrete which will stand on the required slopes, finished with a mortar facing, placed integrally. Expansion joints about 1 in. wide should be placed at intervals of not more than 100 ft. except when the gutter is doweled to a concrete slab, in which case the joints should match those in the slab. The concrete should be thoroughly cured either with calcium chloride or by being kept covered with damp earth or straw. The curing period should be about the same as for a concrete base course.

CURBS

A curb is a small retaining wall which separates the pavement or roadway from the shoulder or parking and holds each in place. A *normal* curb extends above the roadway surface and forms one side of the gutter. A *flush* curb has its top even with the surface of the pavement. An *inverted* curb extends into the subgrade below the pavement base. Curbs are now generally built of concrete although stone is occasionally used.

A normal curb serves two purposes. First, it separates and supports the pavement and the parking. Second, it serves as a guide to traffic. It forms a sharp demarkation at the edge of the pavement, visible to the driver, which aids him in keeping on the roadway. It may also act as flange actually preventing a wheel from leaving the roadway. Many a life has been saved by an adequate curb, although a few fatalities and many a broken wheel can be charged to it. It is better, however, to break a wheel than to kill some one.

Curb Height.—The height of curb should be such as will give a distinct edging to the pavement and form an adequate gutter.

If there is any probability of an additional surfacing course being placed on the pavement in the future, the curb should be of such height that after the new surface is laid a reasonable curb height remains. A low curb is suitable only for very narrow pavements, or at points on wide pavements where it is essential that traffic can cross the curb. The height of the curb materially affects the appearance of a street. If it is too low the pavement appears to be higher than the adjacent ground. If it is too deep the effect is that of a trench.

The normal height should be about 7 in. for ordinary pavement widths. The height may become somewhat greater as the width of pavement increases, but the maximum height is fixed by the necessity for pedestrians to step up and down, or by the height of hub on vehicles. These limit the height to about 10 in. If greater height is required on account of sidewalk or parking elevation, steps must be provided for pedestrians and the curb battered to clear the hubs. A variable height of curb may be necessary to give proper slope to the gutter. The maximum variation in height should not exceed 4 in. and preferably not more than 3 in.

Curb Width.—Stone curbs are usually about 4 in. wide. Concrete curbs are usually 5 or 6 in. wide for the ordinary heights. The latter gives the better appearance for curbs 7 to 10 in. high. Higher curbs or those which may be frequently hit by truck wheels should be somewhat wider. The face of the curb may be vertical or battered. A battered face with well-rounded edges is more convenient to parking traffic and its appearance is better. Unusual conditions of height, traffic, or ornamental consideration may call for different shapes and dimensions.

Subbase.—It is customary to set a curb on a subbase of sand, gravel, or cinders. With a stone curb the subbase is primarily a bedding course to aid in setting the slabs to line and grade and to provide them with a uniform support. With the concrete curb the subbase serves principally as a cheap and convenient method of bringing the subgrade to exact height and shape so as to give a curb of uniform cross-section and support.

Cinders are perhaps the best material for a subbase. They are cheap, easily placed and compacted, do not settle, and are not easily displaced by the concrete during construction. A thickness of 1 to 2 in. is ample.

Stone Curb.—Granite, limestone, and sandstone are the principal varieties of rock used. The stone is split or sawed into slabs 4 to 8 ft. long, 16 to 24 in. wide, and of the required thickness. The ordinary size is 4 by 20 in. The top and face are dressed for appearance and the ends trimmed so that the sections will fit close together. The slabs are placed on edge on the subbase and earth tamped against them to hold them in place. Curved sections must be cut to shape and, therefore, are expensive. Short-radius curves consequently predominate.

The price is quite variable, depending on the kind of stone, the proximity of the quarry, and current demand for materials. Sandstone or limestone 4 by 20 in. cost from $1 to $2 per lineal foot in place and granite about twice as much. Curved sections cost two to four times as much as straight pieces, depending on the kind of stone and the radius.

Plain Concrete Curb.—The plain concrete curb is similar in shape to the stone curb. Its usual dimensions are about 6 by 20 in. The concrete should be 1:2:3 or 1:2:3½ mix and the mortar facing not leaner than 1:2. After building, the curb must be protected and cured, which is best done with a covering of moist earth or straw for a period about the same length as the pavement.

The method of construction is usually as follows: Front and back forms are staked to line and grade. The two are separated by metal division plates set so as to divide the curb into sections 6 to 8 ft. long. The top member of the front form should be a little wider than the height of the exposed face of the curb and is made removable. Stiff concrete that will barely stand after tamping is tamped into the form to the bottom of the removable board. Facing mortar is then plastered against the front form board and the form filled with concrete except for about ½ in. of mortar at the top. The face form board is then removed and the surface finished with float and trowel. Before the finishing is quite done, the division plates are pulled and the edges of the joints thus formed rounded with a *jointer*, after which the finishing is completed. The front edge is rounded to the desired shape with a special trowel and the back edge with an *edger*.

Sometimes the attempt is made to pour the curb with plastic concrete. It is nearly impossible to separate the curb into sections; the face is never true or smooth and the top and edges not well shaped. Sometimes the face and top are rubbed with

carborundum brick which gives an even finish. On the whole, the appearance is not good and almost invariably unsightly cracks develop. The saving in cost is negligible.

The object of the division plates is to provide joints which will control cracking due to settlement and unequal expansion. At the same time these joints add to the appearance of the curb by forming a series of panels which relieve the monotony of the plain surface.

FIG. 12-1.—The deep V-gutter and the combined curb-and-gutter.

In 1934 plain concrete curb 6 by 20 in. on 2 in. of cinders ranged between 50 cts. and $1 per lineal foot with 60 cts. as a fair average price in many localities.

Combined Curb-and-gutter.—The combined concrete curb-and-gutter originated for use with sheet asphalt pavement but it is now used with every type of pavement and with gravel and macadam. The accuracy with which it can be built to line and grade, its great stability against overturning, its reasonable cost, and good appearance, combined with the fact that it adds to the effective width, make it deservedly popular.

The method of construction is similar to the plain curb. A back form for the curb and a front form for the gutter are staked to line and grade. Division plates of proper shape are set in place to divide the curb-and-gutter into sections. Stiff concrete is tamped into the gutter portion to within about ½ in. of the top. A face form for the curb is then clamped against the division plates and plastered inside with mortar. Mortar is

also spread over the gutter flag. Stiff concrete is tamped into the curb section, after which the face form is removed and the gutter struck to shape and grade by means of a straightedge sliding on the division plates. Finishing is then started with

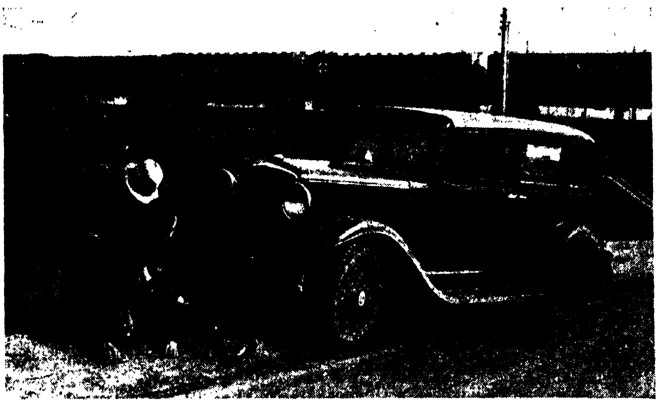


FIG. 12-2.—Safety, not hazards, should be built into a road. A pavement separated from the sidewalk by a shallow gutter with a useless retaining wall in the background. With the retaining wall between the pavement and walk in the form of a curb scenes like this can usually be avoided.

trowels and floats, the division plates are pulled, and the finishing completed. Trowel finish is preferable to float or brush finish, as it gives a denser and smoother surface and a neater appearance. A variation in the method consists of making the vertical legs of the division plates about ½ in. narrower than the width of curb,

FIG. 12-3.—Plain concrete curb and subgrade ready for pavement.

omitting the placing of the finishing mortar on the inside of the front form, and, after the face form is removed, mortar is plastered over the entire top and face of the curb-and-gutter and then struck to shape by means of a *jack* or template sliding on the front and

back forms. The finishing is then completed as before. When it is well done there is no choice between the results obtained by the two methods. The jack saves slightly in labor but is somewhat extravagant in mortar so that the total cost is about the same.

Sometimes combined curb-and-gutter is laid in one course. With low broad curbs the jack may be used for shaping the section. With higher and steeper curbs, better results are obtained by using a front form which is removed when the

FIG. 12-4.—Building combined curb-and-gutter.

concrete has stiffened a little so that the face can be finished with float and trowel. In general, however, good workmanship is hard to obtain with one-course work and this more than offsets any saving in cost or theoretical increase in strength.

Curb-and-gutter may be built either before or after the pavement proper. When built first it makes a very convenient platform from which to control the shape of the pavement or do the finishing of the surface. If the pavement is built first it becomes the front form of the gutter. The curb-and-gutter makes a convenient method of widening and curbing an existing pavement since the gutter flag can be given any reasonable width and reinforced if necessary.

In 1934 curb-and-gutter 24 in. wide with curb 7 in. high and gutter 6 to 7 in. thick on 3 in. of cinders ranged in price from 60 cts. to $1.10 per lineal foot. Some excellent work including ½-in. square steel dowels about 2 ft. apart was built for about 80 cts. A fair price for such work, however, is about 85 cts. under ordinary conditions of labor and materials, including a subbase and the preparation of the subgrade but not the excavation. Straight and curved sections are normally included at the same price although the latter are about 5 percent more expensive to build.

Integral Curb.—An integral curb is one built as a part of a concrete pavement slab or of a concrete base. An integral curb may be normal, flush, or inverted. The inverted curb is used to strengthen the edge of the slab, or for a cutoff wall against underground water. The flush curb is used with a concrete base to retain certain types of pavement against a flush shoulder.

A normal integral curb is built only with a concrete pavement. Sometimes the slab is built and finished in the usual way. The curb is then added by placing a back form for the curb on top of the side form and building the curb up with stiff concrete and mortar, using a template to shape it. Sometimes a front form and softer concrete are used. This method gives good grade to the gutter line but runs the risk that the curb will not bond with the slab on account of the concrete in the slab beginning to set before the curb is placed. Another method is to build the side form to the height of top of curb and shape the entire curb and slab by means of a template, or to use a front form for the curb and shape the surface between them. This method secures perfect bond between curb and slab but makes it difficult to secure a gutter free from pockets which hold water. The curb is not actually divided into sections but the jointer is often used to make false joints every 6 to 8 ft. for the sake of appearance. Expansion joints must be provided and made continuous with those in the pavement.

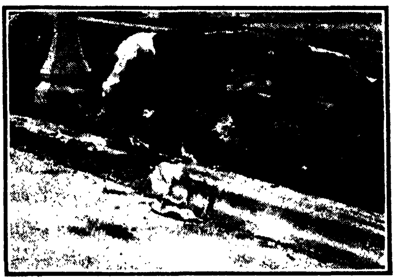


FIG. 12-5.—Building integral curb.

The integral curb was quite popular for a time. The expected saving in cost did not materialize. Difficulties were encountered in doing good work and in obtaining gutters free from pockets which would hold water. In addition it was impossible to widen a pavement without undue expense. New turnouts for drives, etc., were difficult and expensive to make. For these reasons the integral curb is less used now than other types, especially on city streets. It is frequently used for alley turnouts, however, even with other types of main curbs, because the decreasing height enables a saving to be effected. The cost of

integral curb ranges from 30 to 50 cts. per lineal foot in addition to the slab under it.

Lip Curb.—The lip curb is a low triangular integral curb about 3 or 4 in. high and 6 to 10 in. wide. It is built by means of a back form, template, and trowel after the slab is finished but not entirely set. The cost in 1934 was 15 to 20 cts. per lineal foot.

This curb forms a shallow gutter which collects the surface water on the slab and prevents it from flowing along the edge of the slab and washing a rut in the shoulder. It is used on comparatively flat grades, and especially on the inside edge of superelevated curves on grades. The water is discharged into

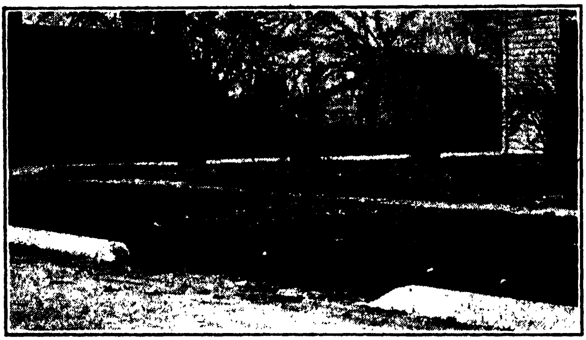


FIG. 12-6.—A crude opening for a private drive.

the side ditch at the bottom of the grade by means of a special *offtake* which offers no obstruction to traffic.

Aside from its aid to drainage and its protection of the shoulder it is a distinct aid to traffic. It makes the edge of the pavement more distinct, tends to deflect wheels touching it, and thus adds to the sense of security of the driver. Running off the slab on to the shoulder is much reduced by its use. This results not only in less damage to the shoulder but also in fewer wrecks due to getting off the solid slab on to a soft surface when running at high speeds.

Driveways.—With stone curbs the custom arose of simply omitting a section of curb to provide an opening for a private drive. This crude method has carried over into the concrete curb (Fig. 12-6) and many cities and some highway departments still disfigure their pavements in this way. Such an opening permits dirt to wash in on to the pavement, does not provide a gutter across the opening, and especially does not furnish a

reasonable or convenient connection if the drive is subsequently paved.

The curb should be turned back on a suitable radius for at least 12 in. from the gutter line and the pavement or gutter flag extended and sloped upward to form a shallow V-gutter across the driveway. This turnout costs little, has good appearance, is sanitary, holds the earth back, and can easily be extended at any time (see Figs. 12-4 and 12-7).

With stone curb and an 8-ft. driveway the straight section omitted will about pay for the short-radius corner pieces. The additional cost of the turnout is then due only to the extra pavement and excavation in the turnout. With plain concrete curb, the amount of curb saved will more than pay for the extra

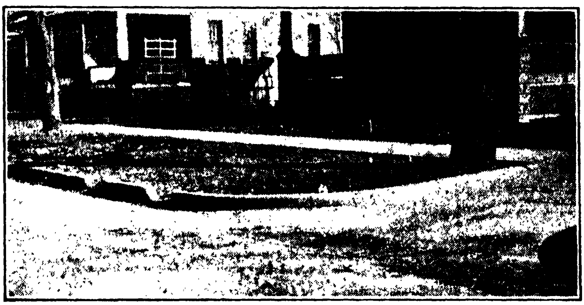


FIG. 12-7.—What happens when curb openings are not regulated. A well-built driveway side by side with two notches broken in the curb.

form work. In fact, in some cases the turnout will actually cost nothing extra, as the cost of the curb omitted will more than equal the extra work and the extra pavement. With curb-and-gutter the additional cost will be for the extra concrete and the extra form work. For an 8-ft. driveway the total additional cost with 4-ft. radii should not exceed \$2 to \$3 or just about the assessment on ¼ ft. of extra frontage. The same work cannot be done subsequently for anything like this price.

The radius of the turnout should be as long as conditions will permit. Business streets may be limited to 2 to 4 ft. so as not to encroach on the sidewalks. On residential streets of ordinary width a radius of about 8 ft. is desirable and 10 ft. is better. With very narrow pavements the radii must be longer to provide space for automobiles to turn into the driveway without striking the curb.

Turnouts on city pavements should be regulated by ordinance. In some states the cost cannot be included in a special assessment except in cases of repaving or widening, but the ordinance can provide for the details of construction. This takes care only of new work and does not cover openings made in existing curbs. It is therefore better to have a separate general ordinance which can be made to cover both turnouts on new work and turnouts cut into existing curbs. It is little short of criminal the way some municipalities permit their curbs and streets to be mutilated.

Doweled Curb-and-gutter.—Experience with curb-and-gutter on concrete pavements shows that frequently the slab and gutter get out of level with each other. To correct this evil, dowels were

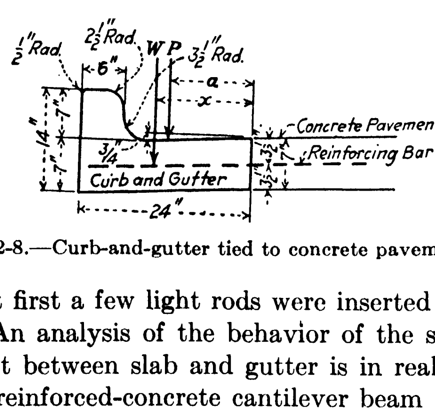


FIG. 12-8.—Curb-and-gutter tied to concrete pavement slab.

inserted. At first a few light rods were inserted as shear members only. An analysis of the behavior of the structure shows that the joint between slab and gutter is in reality the critical section of a reinforced-concrete cantilever beam whose effective depth is one-half the depth of the slab and gutter flag. Tie bars are, therefore, required.

Figure 12-8 shows a typical curb-and-gutter and the conditions of loading. Since the curb-and-gutter is divided into sections which receive little support from each other, each section may be considered by itself. If a longitudinal dowel is used in curb or gutter the same assumption may be made.

The total bending moment per section is

$$M = Wx + Pa$$

in which M is the bending moment in inch-pounds, W is the weight of a section of curb-and-gutter in pounds, x is the distance from the joint to the center of gravity of the section in inches, P is a wheel load in pounds, and a is the distance in inches of this load from the joint.

From the theory of reinforced concrete the area of steel per section is

$$A = \frac{M}{f_s jd} \tag{12-1}$$

in which A is the area of the steel in square inches, M is the bending moment in inch-pounds, f_s is the permissible unit stress in the steel, and j is the ratio of the moment arm of the resisting couple to the effective depth d. The value of j may be taken as 0.85 and, with allowance for unusual loads and possible corrosion, f_s is ordinarily taken at 20,000.

The stress in the concrete is

$$f_c = \frac{2M}{kjbd^2} \tag{12-2}$$

in which f_c is the maximum unit stress in the concrete, k is the ratio of the depth to the neutral axis to the effective depth, which may be taken as 0.40, b is the length of the section in inches, while M, j, and d are the same as in Eq. 12-1.

The length of the bars is limited by the width of gutter flag; therefore the maximum size of bar is such as will develop the necessary bond in this length. As an extra precaution, deformed bars should be used. While small bars at frequent intervals have some advantage over large bars more widely spaced, conditions of placing the bars and possible corrosion make a ½-in. rod the smallest desirable. The bars are placed by boring holes in the front form of the gutter and inserting the bars, supporting them as required. In order to prepare the subgrade for the pavement it is customary to bend the bars up temporarily after the front forms are removed. This bending should be just enough to permit the use of shovels, or not more than 45 deg. This makes a ½-in. square bar, also about the maximum that can be used. This bending should not be permitted for at least 3 days, and preferably longer, after the concrete is placed in order not to disturb its bond with the concrete.

The wheel load to be considered depends on traffic conditions. On residential streets a load in excess of 2,000 lb. is likely to be so infrequent as not to require consideration. On business streets heavier loads may be encountered. The distance a of the wheel from the joint will depend on the width of gutter and wheel. For an 18-in. gutter a will not often exceed 12 in.

If the wheel load is in the middle of the section longitudinally it is sufficient to consider that the load is taken uniformly by the entire section. If near one end the load will not be uniformly distributed; but until further evidence is secured that it is not safe to do so, it may again be considered as carried uniformly by the section. If a continuous longitudinal dowel is used, part of the load will be transferred from section to section and the assumption becomes more nearly correct.

Example.—For the cross-section shown in Fig. 12-8 and a section 7½ ft. long, W is 1,575 lb., x is 13.8 in., b is 90 in., and d is 3½ in. Assuming a wheel load of 2,000 lb., located 12 in. from the joint, the bending moment is 45,735 in.-lb. Substituting in Eq. 12-1 A is found to be 0.95 sq. in. Thus four bars, ½ in. square, 4 ft. long, spaced 22½ in. apart, are required for each section. From Eq. 12-2 the maximum stress in the concrete is found to be 244 lb. per square inch, which is amply safe.

The effect of tie bars is to reinforce both the edge of the slab and the edge of the gutter and produce a structure not unlike an integral curb. The curb-and-gutter becomes a unit with the slab and must be so considered in matters of expansion, etc., and not as an independent structure. Neglecting to take this fact into consideration has resulted in many failures.

To be fully effective both dowel and tie bars should extend straight across the joint. They can be so placed only by making holes in the forms. Contractors object to this, especially with steel forms. The practice has therefore arisen of bending the bars sharply at right angles, wrapping one leg with paper and then burying the bar in the concrete with the wrapped leg against the form. After the forms are removed the bars are dug out and bent across the joint. The bend can never be made so as to give a straight bar so the effectiveness, especially of a tie, is largely lost. In addition, the work may loosen the bar and destroy its value. The forms should therefore be drilled and the bars placed straight. If the form makers would place holes at some standard distance and the engineers adjust the size of bar to this spacing, better results would be obtained.

Expansion Joints.—Stone curbs do not require expansion joints since the spaces between sections are sufficient to take up the expansion. Plain concrete curbs and concrete curb-and-gutters should have joints about 1 in. wide spaced not more than 150 ft. apart. The best joints are made of prepared filler cut to the shape of the curb. A joint is made by setting a strip of filler

in the form in place of one of the steel division plates. The ends of the curb against the filler are finished with an edger. Integral curbs must have expansion joints continuous with those in the slab. The same is true of curb-and-gutter when doweled or tied to a slab.

Care must be taken that the expansion joint extends its full width entirely through the curb or curb-and-gutter. If concrete or mortar bridges the joint the direct pressure, or the squeezing out of the filler is sure to spall the face of the curb or gutter and damage it in both appearance and serviceability.

FIG. 12-9.—Absence of expansion joints causes curb failure.

At intersections, expansion joints are normally put in plain curbs or in curb-and-gutter at the tangent points of the curves. If an inlet is set in the curb, expansion joints should be placed at equal distances on each side of it. If a curb bar is placed over the inlet these expansion joints should be just at its ends. When an integral curb is used, or a curb-and-gutter is doweled to the slab, the expansion joints at the tangents points are omitted and only those joints that are continuous with those in the slab are placed. Since the curb-and-gutter is normally placed first, the expansion joints must be located in it and those in the pavement made to conform.

If a gutter inlet or combined gutter-and-curb inlet is used, expansion joints must be placed at each side of it, or at the ends of the curb bars if they are used. Between these joints the dowels in doweled curb-and-gutter must be omitted. It is good practice to use a narrow expansion joint about ¼ in. wide

between the curb and slab for this distance. Corner and edge reinforcement should then be used in both the slab and gutter, especially in front of inlets or corners, since wheels are very likely to run on the joint.

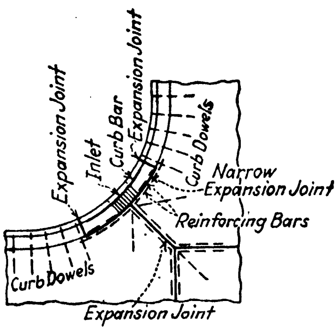


FIG. 12-10.—Expansion joints at inlet in doweled curb-and-gutter.

Curb Bars.—Curb bars are used to protect the edge of the curb from abrasion by traffic. They may be used along the entire length of the curb or only at certain places. This is altogether dependent on whether wheels frequently strike the curb. With vertical-faced curbs it is good practice to use curb bars at all corners. Special shaped bars with anchor fins or loops are manufactured and may be obtained plain or galvanized. The latter are preferable since the curb will not become disfigured with rust stains. The curb bar may cross the ordinary curb joint but must be discontinuous for the full width of all expansion joints.

INLETS AND MANHOLES

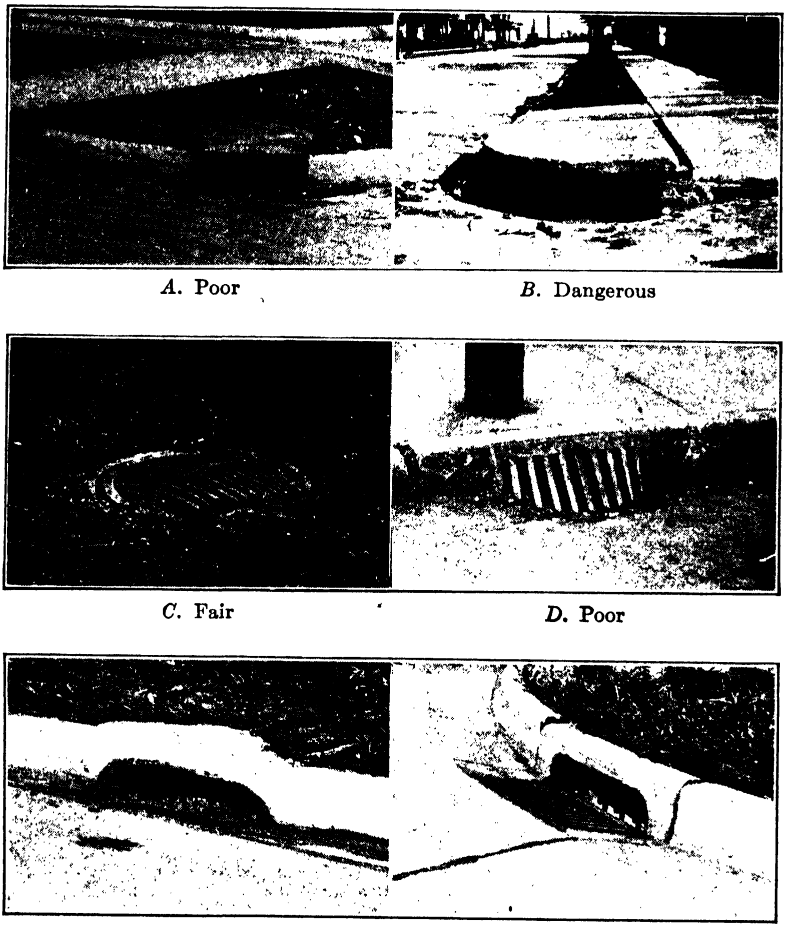
Inlets, catch basins, manholes, gutter turnouts, and offtakes are accessories of the drainage system.

An *inlet* is an opening from a gutter or ditch into a storm drain. The characteristics of a good inlet are (1) large water capacity, (2) freedom from clogging by sticks and debris, (3) reasonable cost, (4) not easily broken, (5) convenient to clean, and (6) of good appearance.

A *catch basin* is a sedimentation basin located between the inlet and the tile, to catch silt, sand, street dirt, etc., and prevent it from entering the drain. A *manhole* is a chamber large enough to admit a man to inspect and clean a drain or sewer. A *gutter turnout* is the place where a gutter turns away from the roadway to discharge into a stream or outlet ditch. An *offtake* is a gutter outlet into a side ditch or stream. It is usually placed perpendicular to the gutter line.

Inlets.—A *gutter inlet* has a horizontal opening in the bottom of the gutter or ditch. It consists of a box of wood, masonry, concrete, or metal, connected to the tile, and provided with a grating cover of wood or metal. A large sewer pipe placed on

end with a cast-iron grating in the bell is often used, especially in rural roads, park drives, etc. On city streets a gutter inlet usually consists of a cast-iron frame, holding a cast-iron grating,



A. Poor *B.* Dangerous

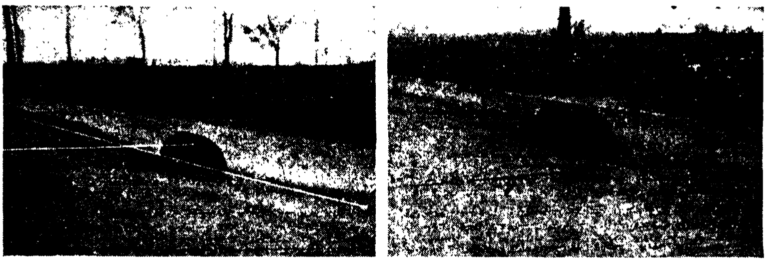
C. Fair *D.* Poor

E. Good *F.* Excellent

FIG. 12-11.—Various types of inlets.

and resting on a masonry or concrete box which connects with the drain by means of a tile. A gutter inlet may be circular or rectangular. A *curb inlet* has a vertical opening placed in the curb. It is rarely used alone but generally is combined with a gutter inlet to give greater capacity and reduce the danger of clogging.

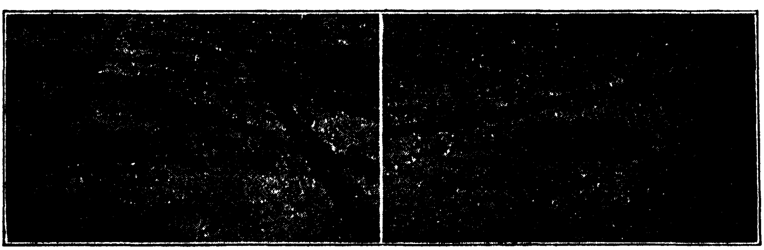
Inlets may be independent and connected to a catch basin by means of a tile or they may be so built as to form a cover for the catch basin. The latter type is used when each inlet has a separate catch basin and the former when several inlets have a common catch basin. The connecting tile should not be smaller



A B

FIG. 12-12.—*A*. Incorrect method of setting an inlet. Note the flat pitch of the gutter grating and the depression in the pavement as shown by the strings. *B*. Correct method of setting the same inlet. Note the straight edge of the pavement slab and the steep pitch of the grating which throws the water toward the curb and helps to prevent clogging.

than 10 in. to avoid clogging with floating debris. The depth of gutter or height of curb at the inlet is usually increased to about 10 in. This calls for additional slope in the gutter which must not be so abrupt as to be disagreeable to traffic. The slope should be made in not less than 6 ft. on each side of the inlet. The front edge of the gutter grating should be set at the normal pavement



Poor Good

FIG. 12-13.—Track inlets.

grade so that a depression is not formed in the pavement opposite the inlet. The increase in gutter depth is obtained by tilting the grating toward the curb. This tilting aids the entry of the water and helps prevent clogging. Figure 12-12 shows the proper and improper setting of an inlet.

Track Inlets.—Inlets should be placed between the rails, and also between the tracks of street railways at the bottom of all sags. These are essentially gutter inlets but must be designed for heavy loads as they are located where wheels are sure to cross them. The ordinary circular or rectangular manhole top with a grating cover makes a good inlet if the pavement is sloped gradually to it as in Fig. 12-13 at *B*. Many special inlets are on the market but many of them are poorly designed. The most common fault is too small size, and the next is to make the grating conform to the crown so that water can enter the inlet only when the pavement and track are flooded as in Fig. 12-13 at *A*.

Manholes and Catch Basins.—Manholes are placed in sanitary sewers and storm drains at each change in alinement, each change of grade, each change of tile size, and at convenient intervals elsewhere for the purpose of inspecting and cleaning the sewer and removing obstructions. The bottom of a sanitary sewer manhole is made with a smooth continuous channel across the bottom so as to prevent the lodgment of putrescible matter. A storm-drain manhole usually extends below the tile to form a *mud basin* and thus transforms the manhole into a catch basin. For this reason the two terms are often used synonymously on storm-drain work.

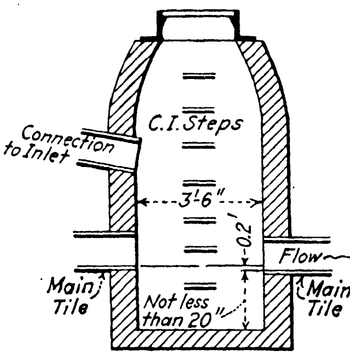


FIG. 12-14.—Typical catch basin of the manhole type.

The manhole should have a normal inside diameter of 3½ to 4 ft. It should be well built of brick, stone, concrete blocks, or concrete cast in place. The top must have a substantial cover. It may consist of a cast-iron ring or frame holding a cast-iron cover plate, or a stone or concrete top with cast-iron cover, or may be combined with an inlet casting. The manhole opening should be not less than 20 in. in diameter. A ladder formed of iron bars imbedded in the wall is provided for men to get up and down. These steps should be of cast-iron as ordinary iron or steel soon rusts out.

Normally the storm drain passes directly through the manhole. If fall will permit, a direct drop in grade of 0.1 to 0.2 should be made at each manhole. The outlet tile should be at least 20 in. above the bottom to provide a reasonable mud basin. Sometimes the drain passes outside the catch basin which is connected to it by a short tile. A trap may be placed in this connecting tile. It is unnecessary with a separate storm-drain system but is often used with combined sewer systems to prevent the egress

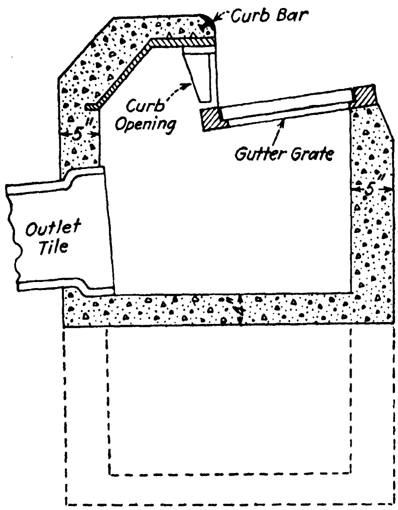


FIG. 12-15.—Concrete inlet box using inlet shown in Fig. 12-11*F*. May be converted into a catch basin by deepening as shown by dotted lines.

of noxious gases in periods of low flow. The trap may be a special fitting but often is merely an elbow on the inner end of the outlet tile with the bell turned downward. A trap is also desirable when an inlet is connected with a farm tile.

A catch basin may be made at each inlet by deepening the box which forms the connection between the inlet and the tile.

Turnouts and Offtakes.—When a gutter diverges from the roadway to discharge into a stream or ditch, the turnout must be so constructed that the water will continue to flow in the gutter and erosion will not occur at the outlet. The change of direction should be gradual and the slope steepened at the same time so that the velocity of the water will not cause it to run past the turn or overflow the channel. Not less than 30 ft. should be used to cross a 6-ft. shoulder. The lining of the

channel should be continued far enough to eliminate all danger of erosion.

At the bottom of a sag where the gutter slopes from both directions, a lateral offtake is necessary. It should have ample width and slope so that the water will flow off without flooding the surface. A full-height curb should be turned back on not less than a 2-ft. radius and the clear opening should be at least 3 ft. wide. With a shallow gutter like that formed by a lip curb the offtake should be wide and shallow and so constructed as to

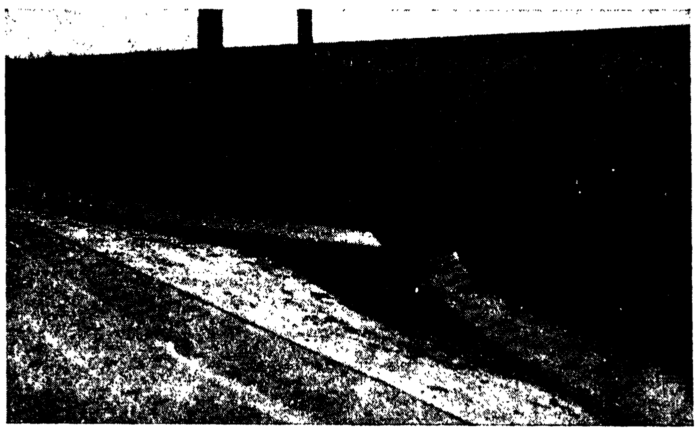


FIG. 12-16.—Offtake from shallow V-gutter. Note the silt due to poor outlet ditch.

offer no serious obstruction to vehicles running on the shoulder. The lower end of the offtake should be carried far enough and be so constructed as to avoid erosion.

STREET RAILWAY TRACKS

Tracks are laid in streets to carry ordinary streetcars, electric interurban service, and, occasionally, steam trains. If the streets are unpaved, ordinary track construction may be used. If paved, special construction is required to minimize the damage to the pavement.

Dimensions.—Standard gage is 56½ in. Streetcars and interurbans are about 10 ft. in width while some steam road equipment is a little over 11 ft. wide. There should be not less than about 1-ft. clearance between cars when they pass. The minimum distance between tracks centers is, therefore, 11 ft. for electric roads and 12 ft. for steam roads. If cars are to pass on

curves, greater distance between track centers is needed to care for the added overhang. This must be worked out for the given conditions of radius, car dimensions, and wheel arrangement.

Loads.—Fully loaded streetcars rarely exceed 40 tons. With 4 axles this means only 10 tons per axle or 10,000 lb. per wheel, which is about the same as a heavy motor truck. Electric interurban passenger cars may exceed 70 tons loaded; and if standard freight equipment is hauled, 80-ton loads, or double that of the streetcar, are not unusual. Street railways in large cities carry comparatively little heavy interurban traffic but have a large number of ordinary streetcars. The smaller city tracks have fewer streetcars and frequently a relatively large amount of heavy interurban service. The real problem of track construction is, therefore, generally in the smaller city where the wheel loads are heavy and the revenues comparatively meager.

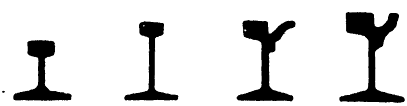


FIG. 12-17.—Rail sections.

Steam road equipment is still heavier. Modern locomotives have wheel loads of about 30,000 lb. per wheel and the cars 20,000 lb. per wheel. Consequently, where steam railroad tracks traverse paved streets, extra heavy track construction is needed. Usually in these cases adequate funds are available.

Rails.—Two general types of rails are most commonly used on street tracks, *viz.*, the *T-rail* and the *girder*, or *grooved*, rail. Figure 12-17 shows two styles of each type. The weights of rail range from 60 lb. per yard for the lighter T-rail to 150 lb. per yard for the heavier grooved rail. Probably the 100-lb. T-rail and 130-lb. grooved rail represent average practice.

The T-rail has the best load-carrying characteristics but has the disadvantage that a flangeway must be formed in the pavement. The grooved rail overcomes this difficulty by having the flangeway in the rail itself. The size of flangeway depends on the style of wheel. Ordinary streetcars require a flangeway about 1⅜ in. wide and 1¼ in. deep. Steam roads and many interurbans use M.C.B. wheels which require flangeways about 1¾ in. wide and 1½ in. deep. Only the larger sizes of girder rail can accommodate the M.C.B. wheels satisfactorily.

The rails may be spliced with ordinary splice bars and bolts or be welded together. Welding can be employed only when the track is imbedded in a heavy pavement which will prevent it from buckling out of line owing to expansion. The welding may be done with oxyacetylene torch, electric arc, or by the thermit process. The rails are usually 45 or 60 ft. long to reduce the number of joints.

Ties.—The rails may be laid on wood, steel, or concrete ties, or on continuous concrete girders tied together with rods. Wood ties are suitable with stone or gravel ballast and are sometimes used in concrete. Only treated ties should be used to secure as long life as possible. Steel ties are suitable for use in concrete ballast. They need not be heavy since they serve principally to hold the rails to gage. The *Dayton tie* is a patented tie consisting of two light steel angles with a creosoted wood bearing block for the rail to rest on. The block is supposed to give some resilience to the track but if rail and tie are buried in concrete the effect of the block is lost and the price might as well be saved. Concrete ties are expensive and are out of place with a concrete base. The usual length of tie is 7 ft.

Ordinary railroad spikes should not be used. They always loosen and permit the rail to rise and fall to the damage of the track and the pavement. If wood ties are employed, tie plates should be used and the rails fastened by screw spikes or bolts. Bolts should be used with other styles of ties.

Ballast.—On unpaved streets, or with gravel and waterbound macadam surfaces, gravel or stone ballast may be used. There should be not less than 12 in. of ballast under the ties and it should be well drained, a special drain being laid just below the ballast if necessary.

On paved streets of all kinds, only a concrete base should be used. With wood ties there should be at least 4 in. of concrete under the ties for streetcars and 6 to 8 in. for interurban and railroad service. With steel ties the base should be at least 6 in. thick. Sometimes two concrete girders about 12 by 12 in. are laid, one under each rail, and the rails bolted to them. The concrete should be not leaner than 1:3:5. It should be poured at a stiff plastic consistency about like pavement base and should have ample curing time before loads are applied. When short time is imperative special cement or rich mixes of portland cement should be used.

Specials.—Track specials of all kinds, such as switches, frogs crossings, etc., should be of the best design with hard (manganese) steel at points of maximum wear. The specials should be accurately located.

Curves should be of as long a radius as possible and should be spiraled. Companies making the special work will build switches to spirals and supply rails so curved.

Paving in Tracks.—The pavement in the tracks may have any kind of surface but some form of block pavement is generally preferred, largely on account of facility in making repairs to the tracks. The area of pavement attributed to the track should be at least as wide as the length of tie. It is frequently specified as 1 ft. outside the rails, which gives a little over 7 ft. With more than one track the entire space between tracks is included.

FIG. 12-18.—Grooved rail meeting a T-rail with a granite block flangeway in a brick pavement. Note the flat crown between the rails.

Usually the primary base or ballast is brought to the base of rail. The pavement structure must then provide for a total thickness equal to the height of rail. This may call for an additional base which is sometimes laid separately and sometimes integrally with the concrete base. The whole track structure should be separated from the body of the pavement by a distinct construction joint, although an expansion joint is not necessary.

The surface is laid in the usual way except that brick, stone block, and wood block are laid with longitudinal courses to avoid excessive batting in. If T-rails are used, a flangeway must be formed which should be as narrow as permissible. The flangeway in block pavements may be made with special shaped blocks or by laying a course flatwise under the head of the rail and then a block in regular position. With concrete or bituminous mixtures the flangeway is often formed by means of a strip of wood, the size of the flangeway laid in place alongside the rail and later removed. In other cases the flangeway is cut in the surface by means of a template.

The head of the rail should be about ⅛ in. above the pavement on the outside. Between the rails the pavement should be flat or with a crown of not more than ¼ in. More crown than this,

especially if combined with a wide flangeway, will make a very rough riding crossing for vehicular traffic crossing at right angles at street intersections. Between tracks the pavement should also be very flat for the same reason.

Solid Construction.—With the advent of concrete pavement came what might be termed solid-track construction. The track is laid with welded rails, on light steel ties, on a concrete base. The base may be laid to the bottom of rail and permitted to harden after which the pavement slab is poured, or the base and slab may be poured in one operation making a monolithic slab in which the rails are buried. Both methods have been tried but time will be required to demonstrate which is worse.

Whatever else may be said for this type of construction, it undoubtedly is about the harshest riding and noisiest track yet placed in our streets. The extreme rigidity of the track is hard on both the rails and the rolling stock, resulting in flat wheels, broken axles, and prematurely worn rails. The noise has caused much complaint and many different devices have been tried, including the substitution of busses for the cars, to overcome the trouble. Some relief is afforded by using a bituminous carpet in the track area but probably the best method is to use some other type of track construction.

SIDEWALKS

A sidewalk is a surfaced pathway for pedestrians. Sidewalks are an essential part of every city street and are required on many rural roads.

Cinders, Gravel, and Broken Stone.—Cinders, gravel, and broken stone are frequently used for surfacing walks along rural roads, on village streets, and in parks and private estates. The thickness of the surface should be about 3 in. or more. Hard boiler cinders form an excellent surface for moderate use and are inexpensive. Any gravel that compacts well and is free from large stones may be used. Broken stone walks are generally laid by placing a layer of crusher-run stone of desired thickness or by placing a layer of screened stone and covering it with stone chips. Stone and gravel walks are sometimes treated with calcium chloride to keep down the dust and occasionally with asphalt or tar. The cost of these walks depends on their dimensions and the local price of materials; little labor is required.

Brick Walks.—Brick walks are made by preparing a bedding course of sand or gravel 2 to 3 in. thick on which the brick are laid and the joints filled with sand. A course of headers on edge is placed along each edge with their tops flush with the remainder of the surface. The brick are laid flatwise, ordinarily in the herringbone pattern, although other arrangements of courses are occasionally found. Hard-burned building brick are generally used. Brick walks were very popular up to about 20 years ago but have been largely displaced by concrete.

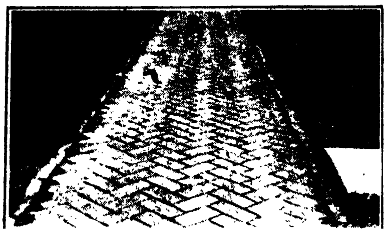


FIG. 12-19.—Brick walk showing herringbone pattern.

Stone Flags.—Flagstones were formerly much used, especially on business streets and for crossings on unpaved streets but have been largely superseded by concrete. The separate stones were 4 to 8 in. thick and of almost any desired size up to 10 by 16 ft. They were set on a bed of sand or fine gravel. In case of an areaway under the walk the slabs were made thicker and supported on the side walls of the areaway. The cost of quarrying and cutting these large slabs make them so expensive that they cannot now compete in price with concrete.

Bituminous Walks.—Walks composed of bituminous mastic, rock asphalt, and similar mixtures were more or less common at one time. They are still occasionally built especially in certain localities but are not generally known and are of minor importance. The mixture is quite similar to sheet asphalt although not so carefully proportioned. Cutback or cold-mix binders may be used. The prepared mastic, either hot mix or cold mix, is deposited between temporary forms and either tamped or rolled to compact it.

Concrete Walks.—Concrete walks have largely superseded all other types. They are pleasing in appearance, smooth, easily cleaned, give good foothold, are reasonable in cost, and can be adapted to practically any location. Lenses can be placed in them to light an areaway underneath which could not be done with stone, and, in addition, the concrete can be reinforced to carry sidewalk loads on nearly any span.

The concrete walk is essentially a thin concrete pavement. It may be built in one course or two courses, the lower one of concrete and top one of mortar. First-class specifications require a pavement mix of 1:2:3 to 1:2½:4 and a 1:1½ to 1:2 mortar top. One-course walks are entirely satisfactory but require somewhat different methods of construction and are somewhat more difficult to make smooth and well finished.

The usual thickness for an ordinary residential walk is 4 in. On business streets and heavy traffic ways, 6 to 8 in. walks are used. If used to cover an areaway, reinforcing is necessary and the required thickness is computed to conform to the span and expected loading. Municipal building codes usually specify the loading. Where ordinary private drives cross, no change need be made in the thickness. Across business drives and alleys where heavy loads occur the thickness should be not less than 6 in., and often more, since the conditions here are practically the same as on the pavement proper.

A subbase is frequently used. The usual material is cinders, although sand, gravel, or stone is sometimes employed. The ordinary thickness of the subbase is 3 to 4 in. but good results have been obtained with 2 in. and some excellent walks have been laid directly on the natural soil. The principal advantage of the subbase is probably in the fact that a firm, stable subgrade giving a uniform cross-section to the walk slab is easily and cheaply obtained. There may also be some merit in the claim of facilitated drainage under some conditions.

Concrete walks are usually cut into sections 5 to 7 ft. square to control cracking due to unequal settlement, expansion, and warping. These joints may be made by means of division plates or by laying alternate sections. Frequently the base course is laid and tamped and then cut through with an ax. The top course is spread and grooves cut with a jointer to coincide with the ax cuts. This is presumed to make planes of weakness but they are not always adequate and cracks may occur elsewhere than in the joints. The finishing is done by hand. Either a trowel or float finish may be used according to local preference. The float finish is possibly a trifle less slippery at first.

Transverse expansion joints ¾ to 1 in. wide, filled with prepared asphalt joint filler, should be placed about every 100 ft. At intersections there should be joints in each walk at the inside line of the intersecting walk and between the walk and curbs as

shown in Fig. 12-20. Longitudinal joints should be placed between curb and walk, between walk and building, or both.

In open ground the walk should be level transversely and should have some crown to facilitate drainage. This crown should be about one one-hundredth of the width. It is customary to tilt the sidewalk toward the roadway to direct the water toward the gutter. This tilt is generally about ¼ in. to the foot but somewhat less would be better. Three-fourths inch in 5 ft. is ample. The crown should not exceed one two-hundredths of the width when the walk is tilted to avoid forming a backslope toward the property and also to prevent the outside half of the walk from having so much transverse slope as to be disagreeable to walk on.

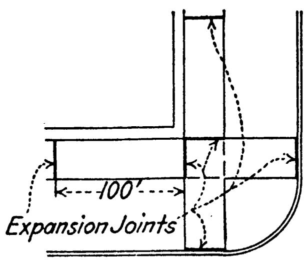


FIG. 12-20.—Expansion joints in concrete sidewalks.

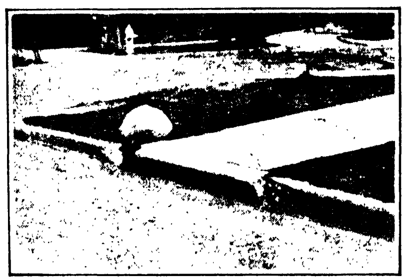


FIG. 12-21.—Result of omitting expansion joints.

In 1934 the cost of a concrete walk of 1:2:3 mix, 4 in. thick, on 2 in. of cinders, ranged from 15 to 25 cts. per square foot with 20 cts. as a fair average. The cost of thicker slabs was about proportional to the thickness.

Location and Width.—Sidewalks are placed adjacent to the property line. On business streets they may cover the entire area from building to curb. On residential streets an open space is left between the walk and curb. On account of fences or buildings the custom exists in many places of setting the edge of the walk in residential districts 1 to 2 ft. outside the property line.

The minimum comfortable width for two persons is about 4 ft., but to allow for passing 5 ft. is the desirable minimum. As the number of pedestrians increases, the walk should be widened as necessary or as space will permit.

Crossings.—Where sidewalks cross unpaved streets, some form of crossing is necessary. A concrete walk may be carried across the street, and sloping wings provided on each side to make

inclines for the wheels. These wings should be 8 to 12 in. wide and drop about 3 in. Brick crossings and stone flag crossings may also be used.

On paved streets the crossings present a conflict of interest between the vehicle and the pedestrian. The simplest and probably the most common method is to run the walk to top of curb, causing the pedestrian to step down into the gutter on one side of the street and up on the other. This is disliked by many and is decidedly objectionable in rainy weather when water is flowing in the gutters. The *raised crossing* overcomes this diffi-

FIG. 12-22.—Raised crossing.

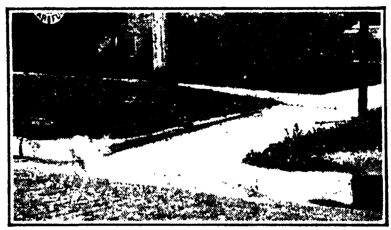


FIG. 12-23.—Ramp crossing.

culty by elevating the pavement to form a cross walk and bridging the gutter with a gutter plate. These crossings were so objectionable to motor traffic that the practice has been abandoned and many such crossings have been removed.

Another method is to elevate the entire pavement intersection practically to the top of curb, thus forming a nearly level crossing. This requires double inlets at many corners as shown in Fig. 5-4 and makes it difficult to prevent vehicles from usurping the sidewalks at the corners. Unless the slope up to this elevated intersection is gradual there may result a bump to traffic similar to a raised crossing. Another type is shown in Fig. 12-23. A small turnout similar to a private drive is made in the curb with radii of about 1 ft. The sidewalk then slopes to this opening, forming a *ramp* instead of a step. This device is much liked in residence districts despite the fact that it is somewhat objectionable in rainy weather.

TREES

Nothing adds more to the attractiveness of a street or road than well-shaped, luxuriant trees. It is not essential that they

give much shade, in fact it is sometimes desirable that they do not, but the foliage in summer adds to the landscape and the leafless boughs break the monotony in winter.

Owing to the demands of modern business and poor growing conditions it is rarely possible to have trees in the main business district. Residential streets, however, should always have trees which ought be carefully selected and cultivated.

Rural roads should also be bordered by trees (see Figs. 1-2 and 9-20). The foliage should not form a shaded avenue but the trees ought to be placed well apart so as not to create too much shade on either road or farm land. In this way the beauty of the landscape is greatly enhanced and becomes a pleasure to the traveler. On east and west roads the majority of the trees may be placed on the south side to avoid shading the farm lands excessively. The rural home should be well planted and the road in front may have an avenue of trees. Variety and not uniformity should be the general scheme in roadside planting.

On a project of considerable magnitude the services of a competent landscape architect should be secured. The engineer, however, should understand the fundamental requirements as an aid in making the design, and in supervising the construction and maintenance.

Varieties.—Many varieties of trees are available. Some are suited to one locality and some to another. It is impossible to include a description of the many suitable varieties here. The reader is therefore referred to *Bull.* 816 of the U. S. Department of Agriculture, which contains some excellent information relative to planting and care. In addition it is suggested that in any particular case the nearest Agricultural College or Experiment Station be consulted.

Spacing.—Probably nothing is more faulty in street planting than the spacing of the trees. The invariable tendency is to get them too close together. When first planted and until they reach a moderate size they appear so far apart, if properly planted, that few people can resist the temptation to put in more. This tendency is also often aggravated by the nursery man who desires to sell more trees. As the trees increase in size, they begin to crowd each other and, thereafter, do not properly develop. It is often suggested that the more permanent varieties be properly spaced and that faster growing and less desirable trees be placed between them and cut out when the desired

trees are beginning to be crowded. This generally does not work out in practice. Experience has shown that popular clamor against cutting street trees is so strong that it takes an unusually hardy municipal officer to carry out a really beneficial program. There are many streets on which a "vandal" would confer a real blessing on the residents by cutting down at least half of their trees.

FIG. 12-24.—A shady street but the trees are too close together to develop properly. Note the cracks in the grouted brick pavement.

Shrubs.—There is little opportunity for the use of shrubs on city streets. Fast-moving modern traffic demands ample sight distance and few of our streets are of generous enough dimensions to permit obstruction by anything unnecessary. Shrubbery, therefore, should be restricted to private property and even here it should be discouraged where it obstructs a reasonable view of the intersection.

On country roads, however, there may be many opportunities for the use of shrubs. Along highly developed agricultural land the possibilities are limited but on the rougher sections many native plants such as the sumac, elder, wild rose, etc., can be encouraged. With a little effort they can be made an attractive feature of the roadside, promoting beauty and forming a refuge for wild life. Many varieties will aid in preventing erosion of slopes of cuts and fills.

Grass.—Grass is a necessary adjunct to a well-kept city street. Rural roads with well-grassed roadsides are also both attractive and easier to keep in good condition. Grassing of embankments, back slopes, shoulders, etc., not only improves the appearance but is economically sound as it aids in preventing erosion, reduces damage by wheels, and restricts the growth of weeds. Many varieties of grass are available. *Bulletin* 816 of the U. S. Department of Agriculture is of value, and further information can be obtained from the various agricultural colleges and experiment stations. Too many trees, or the wrong varieties, may interfere with a good crop of grass.

GUARD FENCES

A guard fence is a safety device placed along the edge of the roadway to protect traffic on bridge approaches, at curves, on high fills, or other points where there is danger of a vehicle running off the road. A guard fence acts primarily as a continuous warning sign past the place of danger. It may also act mechanically to prevent a vehicle from leaving the road. Guard fences are of many styles, suitable to the topography, traffic needs, and local material supplies. In areas subject to drifting snows care must be taken in selecting the type of guard fence and also in placing it, since there is danger that the guard fence will act like a snow fence and make a drift in the roadway where it is not wanted.

Stone Walls.—Where stone is abundant it may be advantageously used for guard fences. Sometimes, a simple row of large stones placed along the edge serves as a warning and may offer some obstruction to a vehicle tending to run off the road. In other cases, a dry masonry wall 2 to 3 ft. high is built. This is both more effective and of better appearance. The most effective and the best appearing, although the most expensive, is a regular masonry wall 2½ to 3½ ft. high. Under favorable conditions stone walls may compare favorably with other styles of guard fences in price. Generally, however, they are much more expensive but their maintenance cost is very low.

Timber Fences.—Timber guard fences are used in many localities on account of their adaptability, high visibility, and favorable price. There are two general types of the timber guard fence.

The *low type* consists of heavy posts set 6 to 8 ft. apart and carrying a single heavy plank set with its middle at the average

height of vehicle hubs (see Fig. 1-2). This type is quite effective as a warning but cannot be depended on to hold a vehicle on the road. On a high fill, however, it fails to give the driver the *sense of security* furnished by the high type. The *high type* is similar in general construction but the posts are taller and carry a second plank, or else a stringer placed on top of the posts. Its main advantage is the increased sense of security already mentioned (see Fig. 14-8). The timber fence is not really effective in holding a vehicle on the road and injuries and fatalities have resulted from splinters and fragments when a car has struck such a fence. Timber guard fences should always be painted to preserve the wood. The posts may be treated, or at least the lower part dipped, to prevent decay.

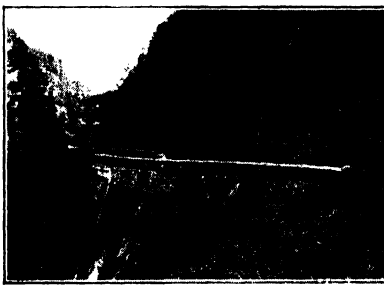


FIG. 12-25.—Stone wall guard fence. Note retaining walls, also.

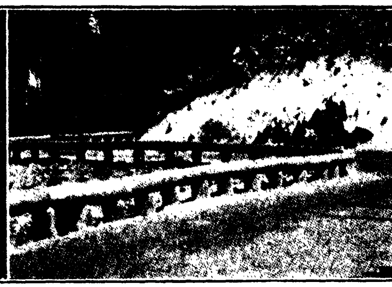


FIG. 12-26.—A rustic guard fence in the timber country.

The low type ranges from about 25 to 60 cts. per lineal foot and the high type from 40 cts. to $1, under different conditions of lumber supply and labor costs.

Concrete Fence.—Concrete guard fences have been tried. They have usually been patterned after the timber types. Although they are quite effective, the costs have generally been too high to make them economical. Sometimes a combination type with concrete posts and timber stringers have been built at fairly reasonable cost.

Wire Cables.—Wire cables are sometimes substituted for the plank stringers. Two or three cables are needed to be at all effective. The visibility is not good and the ability to hold a car that strikes it is little, if any, greater than the plank fence. The cost is greater than for all-wood fences and there is a question whether this added cost is justifiable. The cables are generally $\frac{3}{8}$ to 1 in. in diameter.

Steel Bands.—A comparatively new type of guard fence consists of a band or strip of tough steel attached to the posts with special brackets. The general appearance is similar to the low plank type but it is nearly as effective as the mesh type in holding a vehicle on the road and the cost is about the same.

Wire Fabric.—Guard fences of heavy steel wire fabric supported on concrete or wood posts are gaining in popularity. The mesh is galvanized and often painted as well, in order to preserve it and to increase its visibility. The big advantage of this type over all others is its effectiveness in holding a vehicle to the road. Even a heavy truck will rarely break through it, and the ordinary vehicle is caught and held. In addition, there is no danger from splinters and broken plank, as with the timber fences, or the cutting effect of cables. The cost is about the same as a wood fence. The usual height is about 3 ft. and the cost from 40 to 75 cts. per lineal foot. To increase the visibility on curves a band of sheet metal painted white may be placed along the top edge of the mesh. Sometimes a similar band is placed at the bottom also but this is superfluous. A black stripe 1 to 2 in. wide on this band would increase the visibility.

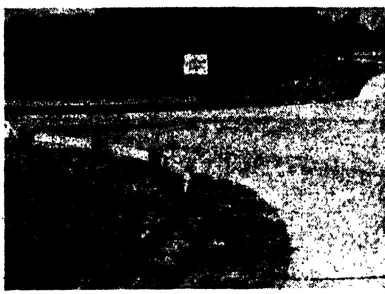


FIG. 12-27.—Steel band type of guard fence.

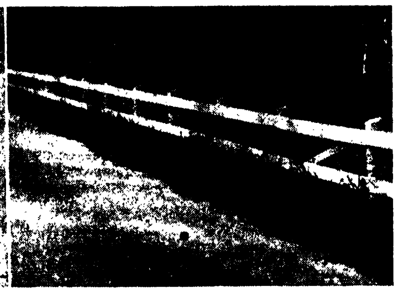


FIG. 12-28.—Wire fabric guard fence. with visibility bands.

Color.—Guard fences should possess high visibility. For this reason they are generally painted white. This color is good except against snow backgrounds. This trouble may be overcome by using treated posts of dark color or by painting a black or other dark-colored band at or near the top of the posts. Light yellow is next to white for this purpose.

RAILROAD CROSSINGS

At grade crossings the space between the rails and outside the rails to the ends of the ties must be floored in a manner which

will provide a good crossing for vehicles, adequate flangeways for the trains, and which can be removed and replaced for track maintenance. Several different kinds of such crossings have been tried. The best are none too good.

FIG. 12-29.—Plank crossing.

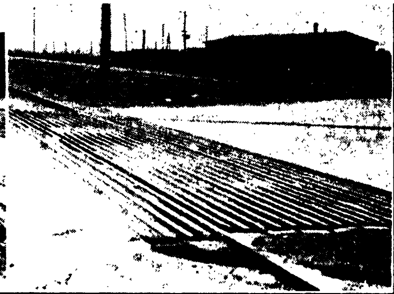


FIG. 12-30.—Rail crossing.

Plank Crossing.—This is probably the most common type. Nailing strips are placed on several of the ties and heavy wooden planks laid to form the crossing. The planks are usually about 3 in. thick. White oak is the preferred wood on account of its wearing qualities but softer treated woods are used to a considerable extent. A single track crossing on a 30-ft. pavement requires about 800 bd. ft. of lumber, and the cost in place, except in the timber country, is \$80 to \$120 per thousand board feet, or 8 to 15 cts. per board foot.

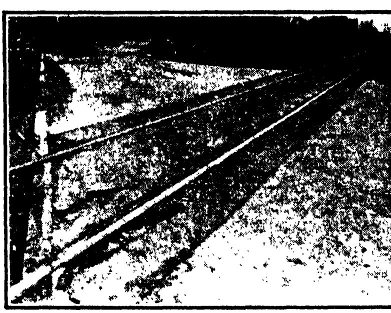


FIG. 12-31.—Bituminous crossing

FIG. 12-32.—Concrete crossing.

Rail Crossings.—A number of railroads are building crossings out of old rails. Supporting strips are placed on the ties and the old rails laid with the heads up. These crossings remain smooth and require little attention. They are slippery when wet or

covered with a film of mud but this is not serious except on skew crossings. No costs seem available on this type because of the use of old rails.

Bituminous Crossings.—Many bituminous crossings have been built. Almost every known type of bituminous paving mixture has been used, including both the hot and cold mixes. The crossing shown in Fig. 12-31 is made of Kentucky rock asphalt. These crossings are resilient and fairly satisfactory under moderate traffic where well maintained.

Concrete Crossings.—Concrete crossings either of precast slabs or of cast-in-place construction have had numerous trials. A few have been fairly successful and many have been failures. Concrete slabs, at least as now made, do not seem adapted to the severe conditions of impact and vibration that exist at railroad crossings. If the life were longer, the concrete crossing might prove economical but at present it cannot compete with plank in most locations.

Problems

12-1. Compute the amount of materials for 1,000 lin. ft. of curb-and-gutter similar to Fig. 12-7 except that the gutter flag is 8 in. thick. Use 1:2:3½ concrete with a 1:1½ mortar face ¾ in. thick (see Table 4-4).

12-2. Compute the size, length, and spacing of tie bars, and also the stress in the concrete, for the curb-and-gutter in Prob. 12-1, assuming the length of section to be 6 ft., f_s = 20,000 lb. per square inch, and a wheel load of 6,000 lb. located 10 in. from the edge of gutter.

12-3. A concrete walk is laid at 70°F. but reaches 120°F. in the summer. Determine the maximum spacing of ¾-in. expansion joints if the joint material can be safely compressed 20 percent (see Chap. 9).

12-4. A single-track railroad crosses a 40-ft. pavement at an angle of 45 deg. A crossing of 3-in. planks is to have a width extending 2 ft. outside the rail heads and provide flangeways about 2½ in. wide. Nailing pieces are to be 4 by 6 in. spaced about 3 ft. apart. Planks can be obtained in widths of 8, 10, and 12 in. and all lumber in lengths of 12, 14, or 16 ft. Make a bill of materials and find the total board feet of lumber required.

12-5. Asphalt concrete is to be used in place of the plank in Prob. 12-4. Specify the composition and make a bill of materials, assuming the rail height to be 6½ in. (see Chap. 11).

12-6. How many board feet of lumber are required for a quarter mile of low guard fence consisting of 8- by 8-in. posts 4 ft. long, spaced 6 ft. on centers, and a 3- by 12-in. hub plank?

CHAPTER 13

RESURFACING, WIDENING, AND REPAIRS

RESURFACING

Resurfacing is the renewing of the pavement surface. It may be accomplished by removing the old surface and replacing it with another of the same or different kind, or by adding a new surface on top of the existing pavement. The former may be termed *resurfacing by replacement* and the latter *resurfacing by addition*. Resurfacing is frequently combined with widening.

Conditions for Resurfacing.—*Smoothness* is the criterion by which pavements are judged. No matter how good a pavement may be otherwise, if the surface is rough, the pavement is condemned by the public as bad. The question of the advisability of resurfacing or of rebuilding must be considered whenever a pavement reaches such a condition.

The primary object of resurfacing, in preference to rebuilding, is to save money or, in other words, to secure the largest salvage value from the old pavement. The mistake is frequently made, however, in assuming that resurfacing always saves money. This is far from true. In each individual case careful estimates must be made to establish the economy of resurfacing.

Resurfacing assumes that the present alinement, width, grade, drainage, curbs, etc., are satisfactory. If they are not, these defects will persist in the resurfaced job and the pavement is not comparable with new work. If changes in any of these items except, perhaps, the width are contemplated, the cost must be estimated and charged against the resurfacing. Correcting faults in the old job often runs the cost of resurfacing very close to and sometimes more than that of complete repavement.

It is fundamental to all resurfacing that the strength of the existing pavement be sufficient to carry the loads. It is not, however, sufficiently indicative if the pavement carries present traffic without obvious failure. Present traffic may be sparse and light in weight owing to the poor surface forcing traffic elsewhere. When the pavement is resurfaced, traffic may seek the

better surface and become dense and heavy. The structure of the pavement must be examined and its value as a base for a new top under new traffic conditions determined.

Designing for Resurfacing.—No surface will last forever, even with first-class maintenance. Every pavement therefore should be designed with the idea of ultimate resurfacing in mind. Renewable top pavements such as brick, sheet asphalt, etc., are frequently chosen on account of the ease of resurfacing when such becomes necessary. The base course should therefore never be skimped.

Curb heights, intersection layouts, inlets, and other details must all be given some consideration to adapt them to resurfacing. This is especially true with concrete pavements which can be resurfaced only by addition.

RESURFACING BY REPLACEMENT

This method is applicable to all types of pavements consisting of a separate base and top. If the base has failed, resurfacing should not be done.

Removing the Old Surface.—Sheet asphalt, bituminous concrete, etc., can be readily removed by means of a blade grader with a scarifier attachment. The old top material is first scarified, then collected into windrows with the blade, and finally loaded into wagons or truck by hand or loading machine, to be hauled away.

Old block surfaces may be removed by loosening the block with picks or plows and then loading them by hand. Occasionally a small steam shovel is employed for both loosening and loading the blocks.

Sand cushions may be removed by working the sand into windrows with a blade grader and then loading into wagons or trucks. If the cushion is to be used again it should be thoroughly loosened, moved into windrows, or piled so that the base can be examined and repaired, and then reshaped.

Repairing the Base.—After the top is removed, the old base should be cleaned by sweeping, with either hand brooms or power sweepers. Sometimes flushing is advisable. The old base should then receive any necessary repairs. At the same time the curb, inlets, drainage structures, or other details and accessories should receive needed repairs and additions.

The base should then be brought to as true a shape as is possible by filling any depressions. If the new surface is to be thinner than the old, as, for example, when sheet asphalt is to replace stone block, it may be necessary to build the old base up to new elevations and cross-sections to compensate for this difference. All such work is best done with material similar to the original base. Thus concrete should be used on a concrete base, a bituminous mixture on black base, gravel on gravel, etc.

When the new surfacing is to be of concrete, there seems to be some difference of opinion as to what should be done. Some engineers prefer to true up the old base just as for any other

FIG. 13-1.—Resurfacing by turning brick over.

FIG. 13-2.—Resurfacing old brick with sheet asphalt.

material. Others claim that good results are obtained by laying the fresh concrete on the old base just as it is. Probably best results would be obtained on very rough bases by some trueing of the surface but this is probably not necessary on reasonably smooth bases.

New Surface.—The new surface may be the same as the original top or of a different type. Very frequently a different type is employed. For example, stone block is often replaced with asphalt, brick, wood, or concrete. It is very common to replace old brick with concrete. This is especially true with old two-course pavements or with brick on natural cement bases. The old brick and cushion can be stripped, giving space for a layer of concrete of such thickness as to be essentially a new pavement.

Every type of new surface is constructed in exactly the same manner as is the same surface on entirely new work. Minor changes may be necessary when old materials such as salvaged blocks or brick are to be used.

Using Old Materials.—Old bituminous materials are rarely used. Sometimes if in good condition, they may be carefully melted and mixed with new materials for the binder course but rarely for the surface.

Old wood block are sometimes culled and those in good condition used in the new surface or retained for repairs. The culled blocks are burned or sent to the dump ground. The old block should be grouped together in the new surface and not mixed with new blocks because the thickness generally is not the same and, if they are mixed, a rough surface results.

Stone block are usually too badly worn to be used again in the pavement. They are often wasted or used for riprap. Sometimes they are crushed and screened for concrete and always make excellent aggregate. The crushing and screening can be done for 50 cts. or less per cubic yard, thus making the cost of the aggregate quite low as compared with new material.

Old brick are especially susceptible of salvage. They may be cleaned and culled and the sound brick used again in the pavement. Old brick should not be mixed with new brick but all the old brick should be placed together for the reasons mentioned for wood block. Instead of being relaid in a pavement the sound brick may be used in building manholes, retaining walls, buildings, or street repairs. Often the old brick can be sold for more than enough to cover the cost of removing and culling.

Old brick may be crushed, screened, and used for concrete aggregate. Even the softer pavers form excellent aggregate for ordinary concrete, while the hard varieties are suitable for almost any kind of work, perhaps including concrete pavements. Experiments have been under way since about 1932 to ascertain the actual merits of crushed paving brick as coarse aggregate in concrete pavements. If the results are satisfactory, a real saving can often be made since a 4-in. layer of brick will form sufficient coarse aggregate for a 6-in. layer of concrete. A number of cities report the cost of cleaning, crushing, and screening at 20 to 40 cts. per cubic yard of aggregate.

Cost.—The cost of resurfacing by replacement is so variable that no general values can be given. The cost of the new surface alone can be estimated the same as the same new work with due allowance for old materials used.

The cost of removing the old surface, except concrete, will cost about one and one-half to two times the current cost of

earth excavation for the same volume and length of haul. The preparation of the base will cost from 2 to 10 cts. per square yard depending on the amount of repairs required. The remainder of the cost is made up of miscellaneous items peculiar to each project.

RESURFACING BY ADDITION

This is the only method applicable to such types of pavements as concrete, monolithic brick, etc., but it may be employed on other types, especially stone block and brick.

The addition of a new top raises the grade of the entire surface. On rural highways the raise of grade is comparatively unimportant since intersections are infrequent and the shoulders can be raised by dirt taken from the ditches. On city streets, however, the new grade calls for grade adjustments with intersecting streets and alleys, and also at private drives, manholes, inlets, streetcar tracks, etc. Additional drainage fixtures may also be required. These are all items of cost chargeable to a resurfacing job and may amount to such a sum that the total cost of the project is as much as or more than the cost of rebuilding the entire pavement. It is the neglect of these items that gives the impression that resurfacing by addition is cheap.

Gravel and macadam are frequently covered with some other type of surface. This might be termed resurfacing but generally is referred to as using the old gravel or macadam as a base. This is in fact the exact status of all resurfacing by addition. The only problems different from those of a new pavement are those peculiar to the process of adapting an existing structure to a purpose not originally intended.

Resurfacing with Asphalt.—One of the favorite methods of resurfacing old brick and stone block is with a bituminous surface, usually sheet asphalt, asphaltic concrete, or Warrenite-Bitulithic. The thickness of such surfaces is the same as in new work so that the old pavement simply becomes the base for the new surface.

The old pavement must be thoroughly cleaned. This may be done by sweeping by hand or power or by flushing. Occasionally special treatment to remove organic matter may be needed. Imperfect cleaning is probably as frequent a cause of failure of this type of resurfacing as any other one thing.

The old pavement must then be brought to a reasonably uniform surface. This may be done by filling the depressions with concrete or with binder of the type used with sheet asphalt. If the depressions are deep, concrete only should be employed. The proportions should be not leaner than 1:3:5 and the aggregate should be smaller than 1 in.

It is typical of all bituminous surfaces that, unless fairly uniform in thickness, they will creep and form waves which are disagreeable to traffic and which ultimately cause holes. It is therefore essential to success that the old pavement be brought to as even a surface as possible.

Ordinary inequalities are filled with bituminous binder, usually of the close type. In making estimates it is customary to figure the amount of surfacing material in the usual way and then make allowances for extra binder to fill the inequalities. A check of a number of jobs reveals the fact that in general the extra binder is underestimated. For brick in fair condition an equivalent of ½ to 1 in. of thickness over the entire surface should be allowed. Three-fourths to one and one-half inches may be required on stone block.

After the base is cleaned and dried and the large depressions filled, the construction is continued as if on new work. With sheet asphalt the binder course is dumped and spread to the specified minimum thickness. The difference between the actual amount of binder used and the amount computed as required for the normal binder course is taken as the amount of *extra binder* required to correct the irregularities of the old pavement. It is paid for at prices ranging from $8 to $12 per ton in place. The binder course is rolled and then the top course is laid and finished as in new work.

Bituminous concrete and Warrenite-Bitulithic are laid as in new work. Sometimes the difference between the estimated amount for the required thickness and the actual amount is paid for as extra binder. This has the advantage that there is no tendency to skimp the thickness.

Connections with existing pavements must be carefully worked out. Generally part of the old pavement must be removed and the base prepared in order that the difference of grade may be adjusted. Frequently additional drainage facilities must be provided. This must be carefully considered in order that the finished pavement will drain properly.

Resurfacing with Brick.—Brick surfaces may be added to any existing pavement including gravel and macadam.

The old pavement is cleaned and the bad depressions filled. Old gravel and macadam may be scarified and reshaped. Other types are repaired or the holes filled with concrete. The new surface is then added exactly the same as on a new job. Monolithic construction using a thin layer of fine aggregate concrete under the brick has been used successfully. In this type, being essentially concrete, the effects of expansion, contraction, and warping enter into the problem and may cause trouble if not provided against. A sand-cement cushion mixture is often used, even with asphalt filler, more adequately to take up the irregularities of the old surface. The best method, however, is to fill

FIG. 13-3.—Adding new monolithic brick top to old brick road.

the large irregularities with concrete and then use an asphalt mastic cushion with asphalt filler applied by the surface-removal method. The cushion should have a minimum thickness of $\frac{3}{4}$ in. which with 3-in. brick makes a minimum of $3\frac{3}{4}$-in. rise in grade which may be difficult and expensive to adjust at intersections, inlets, etc.

Resurfacing with Concrete.—Experience seems to indicate that a minimum of about $4\frac{1}{2}$ in. of concrete is necessary to be stable against its own internal stresses due to climate. Practically, this means that, if concrete is used, a new pavement is laid on top of the old. Such a pavement will be subject to all the effects of expansion, contraction, and warping peculiar to this type of pavement, and since the old pavement may also be quite rigid some of the difficulties are amplified.

If laid on an old pavement to which it bonds, the new slab will be restrained and partake of the behavior of the old pavement and any cracks in the old pavement will reappear in the new. If the old pavement is rough and the two do not bond, expansion may

cause movement between the two, resulting in changed conditions of support which may cause failure. Irregularities in the surface of the old pavement should therefore be filled with concrete which is permitted to harden before the new surface is laid. The new structure may be designed to act with the old pavement by means of suitable expansion joints and reinforcing, or it may be desirable to break the bond with the old surface by a thin layer of sand, earth, or a coat of tar or asphalt so that the new slab is independent.

In general, the resurfacing of city pavements by the addition of concrete is not to be recommended. The grade difference is great; hence connections with drives, alleys, inlets, etc., are difficult. Since the slab is nearly as thick as on a new job, the principal saving is due to not having to excavate the old pavement. This may be more than offset by the cost of adjusting grades and drainage. Note however that this applies to resurfacing by addition. When part of the old pavement is removable making the resurfacing largely by replacement, the problem is different and concrete may be used to advantage.

Cost.—The cost of resurfacing by addition is made up of the cost of the new surface, the cost of preparing the old pavement so as to serve as a base, and the cost of making grade adjustments. The first can be readily estimated but the last two are so variable that no general cost can be given. Careful estimates both of the proposed resurfacing and of an entirely new pavement should be made and compared before a decision is reached.

Miscellaneous.—Practically all types of surfaces may be used in resurfacing by addition. Asphalt is the most used, in fact so much so, that to many the term resurfacing means adding an asphalt or bituminous surface. Asphalt block and wood block have been used to a limited extent. Stone block are rarely employed, while brick have been used in many cases.

WIDENING

The rapid growth in the volume of motor traffic soon demanded wider widths of roadway. In order to obtain them at minimum cost, widening naturally developed, on both rural roads and city streets. In some cases the roadway can be widened on the existing right-of-way but frequently additional land width is also required.

The first consideration in widening is whether the existing surface is worth preserving. The next consideration is whether the widening will actually result in a saving in cost. If the old surface is in good condition and the line and grades are satisfactory, widening is probably advisable. If, however, the line or grades are bad and the surface is in poor condition, it is better and probably cheaper in the long run to remove the old surface and build an entirely new one, except where the widening can be made practically independent of the old work and the latter can later be renewed independently. Furthermore, it is by no means safe to assume that widening will save money. Just as in resurfacing, the incidental costs of adapting the old surface to the new width may make the costs approach, or even exceed, those of an entirely new roadway.

The principal technical problem in widening is that of making a joint between the old and new work of such character that failure will not occur along it. Practically all of the special details peculiar to a widening job are occasioned by this problem.

Gravel and Macadam.—Untreated gravel and macadam are comparatively easy to widen since the new material will readily unite with the old. On feather-edge types the shoulders should have the sod removed and then be bladed to proper shape. A 2-in. layer of new material is then placed on the new subgrade and compacted by traffic and blading. Additional layers are placed and compacted as the preceding one becomes solid, each lapping over on to the old roadway to build up the proper shape. Just before adding the last increment the whole surface, both old and new, should be scarified and the entire new width shaped and compacted as a unit.

Trench types are widened by forming a trench along one or both sides of the old roadway, usually with a blade. The edges of the old part are then loosened and the new portions built up against them in the same way as in new work. Here again it is good practice to scarify and reshape the entire new width just before the final compacting.

Treated gravel and macadam are more difficult to widen. Trench types may be widened in the way just outlined except that the entire surface should not be scarified. In place of this a seal coat covering both the new and the old portions should be applied within a few weeks after finishing the new strips. Feather-edge types should be scarified from the edge to the line where the

new material will extend in overlapping the old portion. After the new width has been placed and compacted, it should receive its treatment and a few weeks later a second seal coat should be given the entire new width.

Concrete Pavements.—Concrete slabs will not unite with each other; consequently the most difficult problems arise in connection with the joint between the old and new sections.

Single-track slabs are often designed for widening. A groove is cast in one edge and the tie bars inserted so that when the additional lane is laid a joint very similar to the regular center joint is formed. When not so designed the new piece is laid

FIG. 13-4.—Excavating under the edge of an existing slab for underpinning—an expensive operation.

alongside the old, often with efforts being made to strengthen the joint or to prevent the slabs from shifting with respect to each other. Generally the old slab is used as one side form for the new portion; hence any irregularities in the old slab are carried into the new. Many widened jobs are unnecessarily rough from this cause. It would be better if the new slab were placed far enough away (10 to 12 in.) from the old slab so that regular forms could be used for both edges. The new slab could then be made smooth since irregularities of as much as an inch could be taken up in the space between the slabs. This space could be filled with concrete or a bituminous mixture. Another advantage of this method is that the old portion could be renewed at any time in the same way.

A two-lane road is often widened to a four-lane by laying a new two-lane strip along one side. Usually the new part is placed against the old, but here again it would be better to separate them as indicated above.

Underpinning is a method of strengthening the joint between the old and new parts. The subgrade is shaped in such a way that the new concrete extends under the old slab a distance of 6 to 12 in. for a depth of 4 to 6 in. This strengthens the joint since the new slab has a thickened edge which also supports the old slab. Obviously the old slab cannot settle with respect to the new. The new slab may settle, however, which not only

FIG. 13-5.—Trueing a widened concrete slab with cement mortar preparatory to adding a brick surface.

makes a difference of elevation between the two slabs but takes away the extra support to the edge of the old slab formed by the underpinning. Underpinning has its merits but it can be carried to ridiculous extremes, especially on narrow strips.

Doweling has also been suggested but is little used. About $1\frac{1}{4}$-in. holes are drilled in the edge of the old slab at intervals of about 2 ft. for a depth of about 4 in. Heavy steel dowels are then inserted in these holes and embedded in the new concrete. This method prevents either slab from settling with respect to the other and strengthens the joint by carrying part of the load across it. It will not prevent the slabs from separating but in this it is no worse than the preceding method.

Concrete Bases.—Pavements of all kinds with concrete bases find the principal problem in the widening of the base.

The surfaces themselves are comparatively easy to widen, since the joint can be made in the same way as an ordinary patch. The base, however, must be widened in much the same way as a concrete pavement.

Widening and Resurfacing.—When an old pavement is both widened and resurfaced the principal problem is again the joint between the new base and the old pavement used as a base. Underpinning or dowels may be used. Sometimes the old portion must be trued up, or excess crown removed. This may be done with a cement mortar or with a bituminous mixture so as

FIG. 13-6.—Widening and resurfacing an old concrete pavement with concrete. Note the expansion joints, the longitudinal joint, and the long tie bars bridging the junction of the old slab with the new earth subgrade.

to provide a smooth, even base for the new surface. When an old concrete or brick pavement is resurfaced and widened with concrete, combined dowel and tie bars at intervals of about 2 ft. are effective in preventing cracks and settlement where the new slab runs off the old slab onto the earth subgrade.

REPAIRS

Whenever for any reason a portion of a road or pavement becomes damaged or destroyed it must be repaired. Repairs differ from maintenance in that the latter presumes a structure in good condition which by maintenance is to be kept so, whereas the former presumes a portion of pavement already in bad condition or destroyed which must be returned to its original condition.

Repairs, however, may shade into maintenance in one direction and reconstruction or resurfacing in the other.

The necessity for repairs may be occasioned by inadequate maintenance, structural weakness, accidental causes, or other engineering work. The last is especially the case on city streets where gas, steam, and water mains, telephone, telegraph, and electric power conduits, storm and sanitary sewers, and their various connections are under the pavement. The construction or repair of any of these may require a cut in the pavement which must later be repaired.

Administration of Repairs.—On rural highways the road officials take care of all repairs. If occasioned by private parties

FIG. 13-7.—Poor backfilling of trenches frequently causes settlement and damage to pavements.

the repairs are made by the officials and the cost levied against the individual responsible.

In city streets the practice early developed of permitting anyone to cut the pavement and also to make repairs. As might be expected, this resulted in many unnecessary cuts which rarely, if ever, were properly repaired. Many good pavements have been practically ruined in this way.

At present no well-regulated city or village will tolerate such practice. Openings can be made only by authorized persons or firms, who must file a bond to cover the costs and to protect the city against damage suits due to accidents. After the work for which the opening is made is completed, the municipal authorities are notified and the repairs are made by the city and the cost charged to the party having the opening made. In this way many openings are avoided and the repairs are well made.

Backfilling.—One of the most important steps is the backfilling of the subgrade. It is obvious that to give proper support the subgrade should be replaced to exactly the same degree of

compactness as it was before being disturbed. This is very difficult to do.

Methods of compacting various soils are outlined in Chap. 5. The method best adapted to the given location should be chosen and then care taken to get the work thoroughly done.

Preparing the Subgrade.—The old pavement should be cut back from the edge of the trench or hole at least 1 ft. on all sides. This is to provide a bearing for the new pavement so as to prevent settlement; or if settlement of the fresh subgrade does occur there will not be an abrupt drop-off between the old and new surfaces. The subgrade is then dug out to a depth of at least 1 in. lower than the old base to provide additional thickness of base over the fill and carefully leveled and tamped.

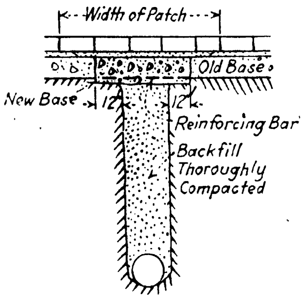


FIG. 13-8.—Typical repair over trench.

Replacing Gravel and Macadam.—Gravel or macadam pavements or pavement bases are then replaced by depositing the material in layers and thoroughly compacting it by tamping or rolling so to make it as nearly as possible homogeneous with the old work. The top should be finished to conform exactly to the grade and crown of the adjacent portions.

Replacing Concrete Base.—The old base should be cut with vertical faces and all loose pieces, dust, and dirt removed. The new concrete should ordinarily be of about the same proportions as the old base. In case the repairs must be opened to traffic in a short time a rich mix or quick-hardening cement should be used. Such concrete will ultimately be harder than the old base but as far as is known this is no detriment.

The consistency of the concrete should be such as can be easily worked into place and finished by hand methods. It should be carefully spaded or puddled into contact with the old concrete. It is sometimes recommended that the old concrete be moistened or given a paint coat of neat cement grout to promote bond with the new, but it is doubtful whether this is necessary or even effective. The top of the concrete should be struck off to conform to the adjacent surface and finished with a wood float. If a bituminous top is to be placed, the surface of the concrete should be scored to give bond. After placing, the

concrete must be protected from traffic and also from drying out until properly hardened. Calcium chloride may be used for curing.

Replacing Concrete Pavement.—The replacement of a concrete pavement slab is very similar to that of a base except for the proportions used and the greater care in finishing the surface. If the old slab contains reinforcement and it is possible to do so, the reinforcement should be kept intact as much as possible so as to extend into the new concrete. Reinforcement similar to that in the old slab should be provided in the new work.

FIG. 13-9.—A cut in a concrete pavement. Note the center joint plate and dowel, the corner reinforcing rods, and the mesh reinforcement.

The surface of the repair should be struck off to conform to the remainder of the slab. A transverse trench may be struck off with the straightedge used crosswise of the trench. A longitudinal trench if not too wide may be struck off the same way but, if it is wider, the strike board should be crowned to correspond to the pavement. Irregular patches can be shaped only by eye and then tested with a straightedge. The concrete should be float or belt finished and properly cured.

Special Reinforcement.—In case of a trench more than 2 ft. wide the base should be reinforced so in case the backfill settles the slab will transfer the loads to the solid shoulder. By making assumptions as to the magnitude and distribution of the loads and the conditions of support it is possible to compute the amount of steel. These conditions are far from definite, however. For ordinary conditions, $\frac{1}{2}$-in. square bars spaced 12 in. apart are adequate for ditches under 4 ft. wide, and 8 in. apart for ditches

6 ft. wide. This steel should be imbedded not more than 2 in. above the bottom of the slab.

Replacing Bituminous Surfaces.—Each of these surfaces is replaced as nearly as possible in the same manner as in original construction. Frequently a light paint coat of bituminous cement is applied to the edges of the cut to aid in making the new work unite with the old. It may be impossible to use a roller on small patches or narrow trenches. In these cases recourse must be had to tamping. This work should be done thoroughly and the surface finished with hot tampers and finishing irons. It is permissible to leave the surface about ¼ in. high to allow for further compacting by traffic.

Fig. 13-10.—Mixed patches do not pay. A wood-block pavement patched with sheet asphalt. The blocks have swelled and shoved the asphalt out.

Bituminous macadam is frequently used for small patches in sheet asphalt, Bitulithic, etc. If well made, they are reasonably satisfactory. Bituminous concrete makes better patches and some of the cold-patch materials are very convenient. Certain emulsified asphalts are excellent for patching work.

Replacing Block Surfaces.—After the base is prepared the cushion should be laid as nearly as possible like the original cushion. A sand-cement patch should not be placed in a sand cushion or vice versa. The block should be laid to complete the original courses. In making the opening, the old block should be so removed that the new block will break joints with the old block at the junction. This is difficult but especially important with grouted brick. The new block must be tamped or rolled to exact conformation with the old surface and a straightedge used to check the surface so that the patch is neither high nor low. The filler should be the same as in the original pavement.

Small Holes.—The treatment of small holes or depressions is one of the most troublesome problems, especially in street work. These holes may develop in any type of surface owing to a variety of causes. When they are of sufficient magnitude, regular repairs can be made but frequently relief is desired before work of this extent is expedient. One of the most satisfactory methods is to fill the hole with asphalt concrete, using emulsified or cutback asphalt. The stone and binder are mixed, usually by hand, in

FIG. 13-11.—Washouts often demand repairs of many kinds.

the proportions recommended by the manufacturers of the asphalt. This is usually about 1 gal. to 1½ to 2 cu. ft. of stone graded ⅜ to ¾. This mixture is then thoroughly tamped into the depression and covered with coarse sand or screenings. It is desirable but not always necessary to protect the patch from traffic for a few hours.

Other cold-patch materials may be used, and in case of a large amount of work a hot-mix outfit may be used. One of the big advantages of the emulsion is the small equipment required. In addition, it seems to possess adhesive properties which make it especially suitable for the small depression with feather edges.

CHAPTER 14

HORIZONTAL ALINEMENT

GENERAL

The position of a road in the horizontal plane is termed its horizontal alinement or, simply, *alinement*. The *center line* is used to fix the alinement.

There are always certain *control points* through or near which a road must pass. Between these points the ideal alinement is straight. Such direct alinement is not always possible owing to prohibitive cost of construction, interference with established improvements, excessive grades or other topographic features.[1] The normal alinement is, therefore, one which consists of a series of tangents connected by curves. The problem is to establish a line that is as direct as possible and is reasonable in cost of construction, maintenance, and operation.

Distance.—Distance adds to the cost of construction and maintenance in direct proportion to the increased length. Since the terminal and standby costs of motor traffic are relatively small, the cost of operation is also practically proportional to the distance. The cost of fuel, oil, tires, etc., varies with the distance and the size and type of vehicle. Overhead costs of depreciation, license, insurance, tires, repairs, etc., vary over a wider range and since the mileage of individual cars is extremely variable these values can be only broadly averaged. T. R. Agg estimates[2] the value of small changes of distance at 2.5 and 3.3 cts. per car-mile for the average automobile on high type and intermediate types of road surfaces, respectively. For commercial vehicles he gives 8.0 and 13.0 per vehicle-mile on the same surfaces but includes an item for the saving in time. Obviously distance affects the time required to travel the road but a small saving in time

[1] *Politics* is another obstacle to direct alinement. Technical problems are often not difficult, while political influence of various kinds is often troublesome to surmount.

[2] See Chap. 18 and Table 18-2; also *Bull.* 91, Iowa Eng. Expt. Sta., Ames, Iowa; also *Proc.* A.S.C.E., Vol. 59, No. 7, p. 1097, or *Trans.*, No. 99, p. 1024.

between two points is valueless because it cannot be profitably utilized. It is only when the saving in time to individual vehicles becomes large enough for each vehicle to make use of it that the saving in time can be evaluated.

Economic Distance.—The economic distance is affected by the origin, destination, and volume of traffic. These data, therefore, are among the most valuable derived from a traffic survey. Relative costs of construction on the different routes must also be considered but with these being equal *the economic distance is that which makes the total vehicle mileage the minimum.*

As an elementary example consider the layout in Fig. 14-1. Assume the traffic on AB to be 1,000 vehicles per day, the traffic

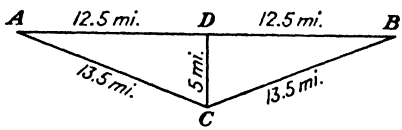


FIG. 14-1.—Direct and indirect routes.

on AC and CB to be 100 per day, the cost of construction to be \$30,000 per mile, and the cost of operation over short distances to be 2.5 cts. per car-mile. At first sight it would appear that ACB is the proper location, since it is only 2 miles longer than AB and accommodates the traffic to and from C, while to build AB and add a spur from D to C would require three additional miles of road costing \$90,000. The traffic comparison, however, is as follows:

Daily traffic via ACB = 1,000 × 27 = 27,000 vehicle-miles
200 × 13.5 = 2,700 vehicle-miles
Total = 29,700 vehicle-miles

Daily traffic via AB and DC =
1,000 × 25 = 25,000 vehicle-miles
200 × 17.5 = 3,500 vehicle-miles
Total = 28,500 vehicle-miles

The direct route AB with spur DC therefore *saves* 1,200 vehicle-miles per day. This amounts to 1,200 × 365 × \$0.025 = \$10,950 per year, or sufficient to pay for the extra 3 miles in 10 years with interest at 4 percent.

The problem becomes more complicated when both passenger and commercial vehicles must be considered and when different

types of surfaces and differences in topography affect the relative costs of construction.

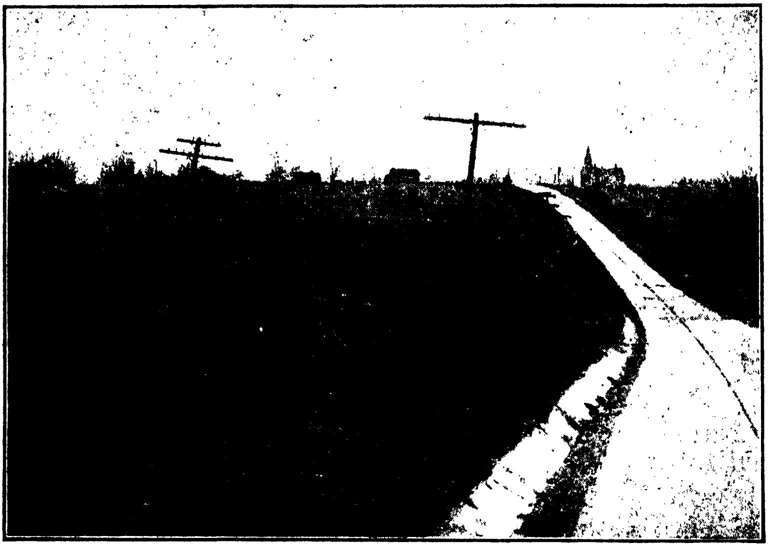


FIG. 14-2.—Relocation to secure direct alinement.

Diagonal Routes.—The rectangular road system found in many places serves local needs quite well but is often expensive for trunk roads, and large savings can often be effected by relocation on the diagonal. The new line will be shorter than the old and therefore will cost less to construct, maintain, and operate. New right-of-way will be required which will add to the first cost.

FIG. 14-3.—Diagonaling.

For any given angle the various costs can be determined and the net advantage of the diagonal computed. As an example, assume the conditions in Fig. 14-3, a cost of construction of $30,000 per mile and a right-of-way 66 ft. wide. The saving in distance is $^{15}/_{16}$ mile which reduces the cost of construction by $28,125. The amount of new right-of-way is $64\frac{1}{2}$ acres. This would permit a price of about $436 for the land without changing the first cost. With a daily traffic of 1,000 vehicles per day at 2.5 cts. per mile, the daily saving in traffic cost is $^{15}/_{16} \times 1{,}000 \times 0.025 = \$23.44$, or about $8,550 per year. It is thus evident that

FIG. 14-4.—Development to secure easy grades. The Rowena Loops on the Columbia Highway in Oregon. Asphaltic concrete surface on 5 per cent maximum grade.

even slight diagonaling may be done at little if any additional first cost and always yields a definite saving in cost of operation.

Distance and Grades.—Distance is frequently increased to avoid excessive grades. The cost of the excess distance must be balanced against the excess cost of the steep grade. The method of estimating the cost of excess grades is outlined in Chap. 15.

Curvature.—A large amount of curvature indicates a considerable departure from a direct line and hence added cost of construction and operation. Curves probably add slightly to the tractive resistance and to wear on vehicle and road surface, especially if not adequately superelevated, but so far the effect has not been evaluated and is probably quite small except on very sharp turns. Curvature therefore can be neglected as far as cost of operation in concerned. Likewise, compensation of grades for curvature is unnecessary.

Curvature on highways is of most importance from the standpoint of safety and convenience rather than cost. While the total central angle exerts little influence on the cost of operation, it does add considerably to the problems of safety, convenience, traffic regulation, etc. Much unnecessary curvature is to be found in our highways due largely to careless location or unwillingness to relocate and obtain new right-of-way.

Curvature must have an obvious reason for its presence. Everything in nature tends to move in straight lines until deflected by an outside force. Curvature without an apparent cause therefore is fundamentally wrong. The curve, of course, only unites the two tangents, but there must be some obvious reason for the change of direction.

Superelevation.—In order to reduce the disagreeable side thrust and resultant danger of skidding, the road is *banked* or *superelevated.* Theoretically, the amount of superelevation is such that the resultant of the weight and centrifugal force is normal to the road surface. Equating the centrifugal force to the component of the weight down the slope and reducing we find

$$e = \frac{0.067S^2}{R} \tag{14-1}$$

where e is the cross slope in feet per foot of width,[1] S the speed in miles per hour, and R the radius in feet.

[1] The superelevation is often given in inches per foot of width in which case the equation is $e = \frac{0.8S^2}{R}$. It seems hardly consistent, however, to

Since the superelevation varies with the square of the speed and it is possible to build only fixed superelevation into the road, it is evident that such superelevation is correct for only one speed. At higher speeds there is an unbalanced outward thrust and at lower speeds an inner thrust which may be disagreeable at any time and even dangerous, especially on a slippery surface. The trend in motor car design since 1930 has been toward softer springs, especially in front, and low pressure tires. The effect of this has been to accentuate the disagreeable feature of deficient superelevation and length of runoff.[1] So pronounced has been this effect that several manufacturers have installed a so-called "stabilizer" to make the rear springs act together to reduce the tilt—a result formerly resulting from the stiff front springs.[2]

For these reasons every curve should have as long a radius as possible in order that ample superelevation can be had for high speeds without making the tilt too great at low speeds. The speed for which superelevation is provided should be the normal maximum speed of the majority of the traffic at the particular location. There seems to be no good reason why tilts of 0.15 ft. per foot of width, or even more in some locations, cannot be used despite the common practice of limiting them to 0.08 to 0.10 ft. per foot.

Runoff.—Since it is impossible to insert the superelevation suddenly, it must be obtained in a convenient distance termed the *runoff*. The full amount of tilt is required at not more than a car length from the end of a circular curve; consequently all, or the greater part, of the runoff is placed on the tangent. If the runoff distance is too short the appearance is bad and there is a disagreeable lurch to the car on entering or leaving the curve. If it is too long the appearance is again bad and there is a disagreeable tilting of the car before the curve is reached. In both

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figure it in inches when it is always located in the field with a level and a rod graduated to decimals of a foot.

[1] Calculations, checked by observation, revealed the fact that with a typical 1933 car on a 6-deg. curve superelevated for 35 m.p.h. the *car seat* was actually level at about 55 m.p.h. and had an adverse tilt at higher speeds.

[2] For an interesting discussion of these subjects as related to skidding see Skidding Characteristics of Automobile Tires on Roadway Surfaces and Their Relation to Highway Safety, *Bull.* 120, Iowa Eng. Expt. Sta., Ames, Iowa, 1934.

cases the tilt on the tangent tends to throw the vehicle to the inside of the curve which must be overcome by a sensible effort on the part of the driver. Much of the so-called "cutting corners" is the result of this tilt on the tangent rather than of poor driving. These effects are emphasized by soft car springs and low-pressure tires.

All of these difficulties can be eradicated by the use of *spiral* transition curves at the ends of the circular curves. The spiral increases its curvature uniformly from zero at its start to that of the main curve. By making the runoff agree with the length of spiral the superelevation and the curvature are at all times in accord, which results in good appearance, good riding qualities, and easy steering.

The best railroad practice indicates that the desirable length of spiral, and therefore the desirable length of runoff when the curve is fully superelevated, is given by the equation

$$L = \frac{5S^3}{R} \tag{14-2}$$

where L is the length in feet, S is the speed in miles per hour, and R is the radius of the circular curve in feet. This equation seems to give spirals that are unduly long for highway curves. This is probably due to the facts that we habitually drive at greater excess speeds on highway curves than is permitted on the railroads, and that we are accustomed to more rapid tilts in a motor car than in a railway car. R. A. Moyer[1] suggests an equation in practically the form

$$L = \frac{1.6S^3}{R} \tag{14-3}$$

This equation is based on the maximum comfortable rate of changing direction and therefore gives the *minimum* acceptable length of spiral. A longer spiral should be used whenever possible for greater comfort and also for increased safety at excess speeds.

The author suggests the following equation for normal use

$$L = \frac{3S^3}{R} = \frac{DS^3}{1910} \tag{14-4}$$

The value of S to use in any of the preceding formulas should be the normal speed of the majority of traffic at the given location.

[1] *Bull.* 120, Iowa Eng. Expt. Sta., Ames, Iowa, 1934.

TABLE 14-1.—THEORETICAL SUPERELEVATION

Transverse slope per foot of width

$$E = 0.067 \frac{S^2}{R}$$

Speed, miles per hour	Radius, feet (above) Degree of curve (below)																		
	50	60	75	100	150	200	300 19°06′	400 14°20′	500 11°28′	600 9°33′	700 8°12′	800 7°10′	900 6°22′	1,000 5°44′	1,500 3°49′	2,000 2°52′	3,000 1°55′	5,000 1°09′	10,000 0°34.4′
5	7/16 **0.034**	5/16 **0.028**	1/4 **0.022**	3/16 **0.017**	1/8 **0.011**	1/8 **0.008**	1/16 **0.006**												
10	1 5/8 **0.135**	1 5/16 **0.112**	1 1/8 **0.090**	13/16 **0.067**	9/16 **0.045**	7/16 **0.034**	1/4 **0.022**	3/16 **0.017**	3/16 **0.013**	1/8 **0.011**	1/8 **0.010**	1/8 **0.008**	1/16 **0.007**	1/16 **0.006**					
15	3 5/8 **0.303**	3 **0.253**	2 7/16 **0.202**	1 13/16 **0.151**	1 3/16 **0.101**	15/16 **0.076**	5/8 **0.050**	7/16 **0.038**	3/8 **0.030**	5/16 **0.025**	1/4 **0.022**	1/4 **0.019**	3/16 **0.017**	3/16 **0.015**	1/8 **0.010**	1/16 **0.007**	1/16 **0.005**		
20	6 7/16 **0.538**	5 15/16 **0.495**	4 3/16 **0.359**	3 1/4 **0.269**	2 3/16 **0.180**	1 5/8 **0.135**	7/8 **0.090**	13/16 **0.067**	5/8 **0.054**	9/16 **0.049**	7/16 **0.038**	7/16 **0.034**	3/8 **0.030**	5/16 **0.027**	1/4 **0.018**	3/16 **0.013**	1/8 **0.009**	1/16 **0.005**	
25	10 1/8 **0.842**	8 7/16 **0.701**	6 3/4 **0.562**	5 1/16 **0.421**	3 1/4 **0.271**	2 1/2 **0.211**	1 11/16 **0.140**	1 1/4 **0.105**	1 **0.084**	1 1/16 **0.070**	3/4 **0.060**	5/8 **0.053**	9/16 **0.047**	1/2 **0.042**	5/16 **0.027**	1/4 **0.021**	3/16 **0.014**	1/8 **0.008**	1/16 **0.004**
30				7 1/4 **0.606**	4 7/8 **0.405**	3 5/8 **0.303**	2 3/16 **0.202**	1 13/16 **0.151**	1 7/16 **0.121**	1 1/4 **0.101**	1 1/16 **0.037**	15/16 **0.076**	13/16 **0.067**	3/4 **0.061**	1/2 **0.040**	3/8 **0.030**	1/4 **0.020**	1/8 **0.012**	1/16 **0.062**
35					6 5/8 **0.550**	4 15/16 **0.413**	3 5/16 **0.275**	2 1/2 **0.206**	2 **0.165**	1 5/8 **0.137**	1 7/16 **0.118**	1 1/4 **0.103**	1 1/8 **0.092**	1 **0.082**	1 1/16 **0.055**	1/2 **0.041**	5/16 **0.027**	3/16 **0.016**	1/16 **0.082**
40						6 7/16 **0.538**	4 5/16 **0.359**	3 1/4 **0.270**	2 9/16 **0.216**	2 3/16 **0.180**	1 7/8 **0.154**	1 5/8 **0.135**	1 7/16 **0.120**	1 5/16 **0.108**	7/8 **0.072**	5/8 **0.054**	7/16 **0.036**	1/4 **0.022**	1/8 **0.011**
45						8 3/16 **0.682**	5 7/16 **0.454**	4 1/16 **0.340**	3 1/4 **0.273**	2 3/4 **0.227**	2 5/16 **0.195**	2 1/16 **0.170**	1 13/16 **0.151**	1 5/8 **0.136**	1 1/4 **0.091**	13/16 **0.068**	9/16 **0.045**	5/16 **0.027**	1/8 **0.0135**
50							6 3/4 **0.562**	5 1/16 **0.421**	4 1/16 **0.337**	3 3/8 **0.281**	2 7/8 **0.241**	2 1/2 **0.211**	2 1/4 **0.187**	2 **0.168**	1 5/16 **0.112**	1 **0.084**	11/16 **0.056**	7/16 **0.034**	3/16 **0.017**
60								7 1/4 **0.602**	5 3/4 **0.482**	4 13/16 **0.402**	4 1/8 **0.345**	3 5/8 **0.302**	3 3/16 **0.268**	2 7/8 **0.241**	1 15/16 **0.161**	1 7/16 **0.121**	15/16 **0.080**	9/16 **0.048**	1/4 **0.028**
70									7 7/8 **0.656**	6 9/16 **0.547**	5 5/8 **0.468**	4 15/16 **0.411**	4 3/8 **0.365**	3 15/16 **0.328**	2 5/8 **0.219**	2 **0.164**	1 5/16 **0.109**	13/16 **0.066**	3/8 **0.033**
80										8 9/16 **0.715**	7 3/8 **0.614**	6 7/16 **0.537**	5 3/4 **0.477**	5 1/8 **0.429**	3 7/16 **0.286**	2 9/16 **0.215**	1 3/4 **0.143**	1 **0.086**	1/2 **0.043**
90											9 5/16 **0.777**	8 1/8 **0.679**	7 1/4 **0.603**	6 1/2 **0.543**	4 5/16 **0.362**	3 1/4 **0.271**	2 3/16 **0.181**	1 5/16 **0.109**	11/16 **0.055**
100												10 1/8 **0.838**	8 15/16 **0.744**	8 **0.670**	5 3/8 **0.447**	4 **0.335**	2 11/16 **0.223**	1 5/8 **0.134**	13/16 **0.067**

Bold-face figures give decimals of a foot, light-face figures in inches.

On the open road this should probably be 50 to 60 miles per hour.

Any equation should be interpreted as giving merely an approximate length from which a suitable spiral, convenient to compute and locate, is selected. In this connection it may be emphasized that the computations and field work are simplified by using a suitable rate of change of curvature rather than an arbitrary length.

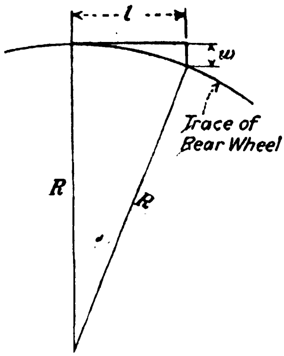


FIG. 14-5.—Widening on curves.

Widening.—Observation has shown that except at excess speeds the rear axle of a motor vehicle remains practically radial as the vehicle traverses the curve. Since the car frame is rigid, the front wheels must travel on a curve of larger radius than do the rear wheels. The pavement must, therefore, be widened on curves to provide the same clearance between vehicles as exists on tangents.

Since the length of the vehicle is short, the amount of widening may be taken as the tangent offset for the given radius in the length of the vehicle. Thus from Fig. 14-5

$$w = 2 \times \frac{l^2}{2R} = \frac{l^2}{R} \tag{14-5}$$

where w is the widening in feet for a *two-lane* road, l the length of the vehicle in feet from the rear axle to the front bumper, and R the radius of the curve in feet. R may be taken as the center-line radius.

There should be an additional clearance due to the fact that it is more difficult to judge clearance on a curve than on tangent. The amount is very difficult to estimate and appears to vary with the speed and radius. James T. Voshel has suggested a formula[1] which can be reduced to the form

$$w = \frac{l^2}{R} + \frac{35}{R} \tag{14-6}$$

in which w, l, and R are as before. The first term may be considered the *mechanical* widening, while the second term gives the

[1] *Public Roads*, Vol. 8, No. 2, p. 35, March, 1927.

psychological widening. This formula seems entirely satisfactory. On curves with more than 500-ft. radius ($D = 10$ deg. or less) no widening is usually provided.

The widening should be placed on the inside edge of the pavement. The full amount is required within about a car length on the curve. This means that the widening must be run out on the tangent. The distance is usually made the same as the superelevation runoff. Where spirals are used, the widening begins at the beginning of the spiral and increases uniformly to the full amount at the junction of spiral and circular curve. This adds to both the convenience and the good appearance of the road.

Sight Distance.—The sight distance is the maximum distance at which two vehicles are mutually visible. Safety demands

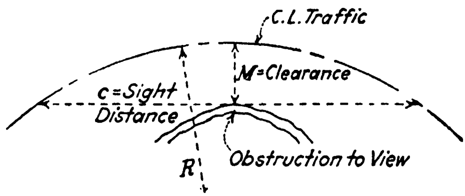


FIG. 14-6.—Sight distance.

that this distance be ample for the vehicles to clear each other at the maximum road speeds. This means that the curvature should be as flat as possible. Experience dictates a minimum sight distance of about 600 ft.

As shown in Fig. 14-6 the sight distance can be taken as the length of a chord to the given curve corresponding to a middle ordinate equal to the distance from the center of the roadway to the object which obstructs the view. Or, conversely, the minimum distance between the center of the road and an obstruction to view is the middle ordinate corresponding to the required sight distance and given radius. The relation is given by the following approximate equation:

$$M = 0.000022C^2D = \frac{0.125C^2}{R} \tag{14-7}$$

in which M is the clearance in feet, C is the sight distance in feet, D is the degree of curve in degrees, and R is the radius in feet.

Figure 14-9 shows a method of providing sight distance on a sharp curve with a high bank on the inside. This is termed

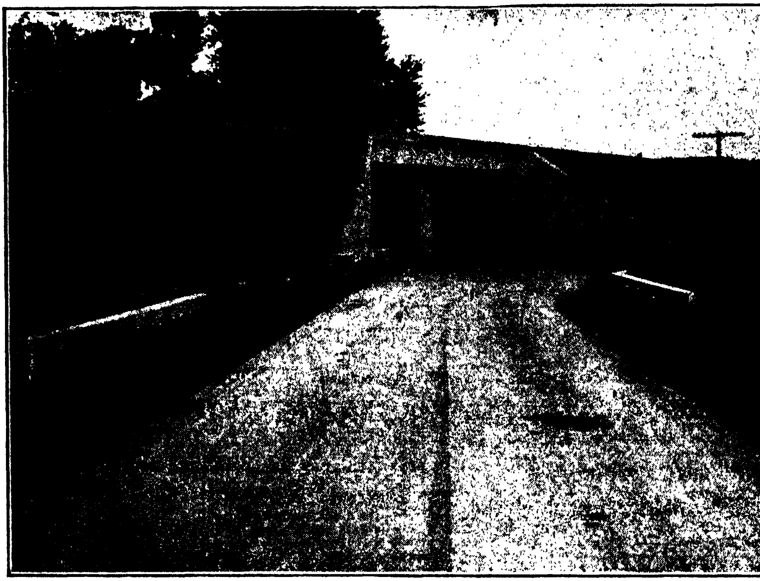


FIG. 14-7.—Bad alinement at subway restricting sight distance. The structure was built in 1906 when little consideration was given highway alinement. Note the center support in the subway. Replaced in 1935 to provide better alinement and sight distance.

FIG. 14-8.—Modern alinement at subway to give good sight distance. Built in 1924. Note also the absence of a center support in the subway.

daylighting. The result would be much improved by cutting to the line ACD instead of $ABCD$. The additional cost would not be prohibitive, the appearance would be better, and the sight conditions greatly improved, since the berm BC may grow up with weeds or brush which are just as effective in obstructing the view as was the original earth.

On winding roads, ample sight distance should be provided at reasonable intervals by means of tangents between reverses, by

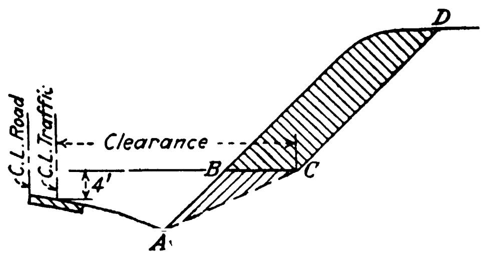


FIG. 14-9.—Daylighting curves.

flat curves, or by daylighting so that faster vehicles may have an opportunity to pass the slower ones.

TRUNK LINES THROUGH MUNICIPALITIES

The routing of a trunk highway through a municipality is an integral part of the highway and must be given careful consideration. In fact it deserves perhaps more care than any other part and certainly much more than it ordinarily receives. All too frequently the rural road authorities are content to hit the city limits at the point most convenient to themselves and leave it to the traffic and the city to take care of the situation the best they can. Unfortunately, too, this condition is often aggravated by the selfish interests of politicians and local business men.

A highway which adds unnecessary distance, inconvenience, or danger to traffic inside a city is just as much at fault as one which has these defects outside the city.

Traffic.—From the standpoint of the municipality, traffic may be divided into four classes. *Terminal traffic* has its origin or destination in the given city. It demands convenient access to the business district or local terminals. *Through traffic* passes through the city without stopping. It desires short, direct routes free from congestion and delay. *Transient traffic* is traffic that ultimately passes through but makes stops of greater or less

duration on the way. In most respects it is similar to terminal traffic. *Local traffic* circulates only within the city. It desires as little interference as possible with the other classes. The route of a trunk highway therefore should be selected so as to give these results as nearly as possible to all kinds of traffic but with preference given to the class of traffic in excess. In every case freedom from interference by or with local traffic should be kept a minimum.

Traffic Centers.—Terminal traffic may be considered as concentrating at one or more traffic centers. These are usually points in the business districts, although occasionally other things establish a traffic center. Terminal traffic demands direct and convenient routes to these traffic centers, while through traffic desires to keep away from them.

In the small village, where distances are short, the trunk road should pass along the edge and a spur extend to the business section. In moderate cities the trunk line should approach the business district but if possible should not traverse the principal business streets. In larger cities, or in any city where the streets are narrow or congested, bypasses or belt routes should be provided.

Junctions.—Different routes frequently enter or traverse the same city. Ease of transfer of traffic from one to another demands that these routes be brought together. This will often have considerable influence on the selection of the proper routing. It also involves proper marking.

Selection of Route.—The first step in the problem is to determine a point on each side of the municipality where the location is fixed by other consideration than the given city. The next step is to study each available entry to the city from either side and the connecting streets inside. The traffic centers should be located and the through and terminal traffic estimated. Other things being equal, the proper route is that which requires the minimum traffic miles. Although the rural road authorities may have to take the initiative, the route should always be selected in conference with the municipal authorities.

STREET PLANS

American cities, almost without exception, have grown up in a haphazard fashion without a definite street plan. Originating, generally, as trading posts at the intersection of routes of trans-

portation, cities have largely developed along lines of least resistance with the original traffic lanes as the skeleton. In rough territory, the streets naturally followed the topography, resulting in a very irregular street layout. In flat country, especially after the introduction of the rectangular land survey, the streets were laid out gridiron fashion. There being little or no supervision, however, each real estate promoter laid out his addition as his fad, fancy, or avarice dictated. The result of all this is a chaotic condition in most of our cities which has been aggravated by the enormous increase in street traffic.

Rectangular System.—The rectangular system is laid out in conformity to the land survey or with a main road, railway, or water front as the major axis. It divides the territory into rectangular blocks and these into rectangular lots. The street angles are rarely exactly 90 deg. especially when based on land survey lines but the error is usually less than 5 deg.

The principal advantages of the rectangular system are (1) straight streets, (2) right-angled intersections, (3) convenient shape of lots and freedom from irregular shapes, (4) maximum possible utilization of the land, (5) convenient numbering system for buildings, and (6) ease in locating a desired number.

The principal disadvantages are (1) lack of conformity to topography, often introducing excessive grades, (2) lack of direct communication from the outskirts to the center. In flat territory the first of these is unimportant. The second is relatively unimportant in the average city although it may be important in large cities, say those in excess of about 100,000 population.

Diagonal Streets.—To overcome the lack of direct access to the business center, or to provide short routes between important points, diagonal streets are introduced. The diagonaling, however, is not always all pure gain in business areas. Irregular lots and blocks occur which do not lend themselves to maximum development. Intersections are increased in size and made irregular in shape, which increases the difficulties of traffic control and reduces the speed of traffic. It is quite probable that in a number of cases the saving in time and fuel, due to the shorter distance on the diagonal, is more than lost in the delay at intersections. On the other hand, a diagonal street carrying a large volume of traffic through an intermediate district may be highly desirable and economical. In the smaller city such diagonals

are of less importance and unless provided in the original plat rarely can be financed, even if economically desirable.

A few cities have been planned with a radial system of primary streets superimposed on a rectangular or subradial and circumferential layout of secondary streets. If the business district does not change position but grows in all directions, this is an excellent system. Unfortunately business districts have a habit of gradually moving, with the result that some of the benefits of the radial streets ultimately are lost.

Alleys.—Nearly every plat formerly provided alleys. In the business district they gave access to the rear of the business houses and removed loading and unloading from the streets proper. In residence districts they gave access to stables at the rear of the lots where horses and often other animals were kept.

The modern business district may still employ alleys or substitute for them interior courts connected by drives to the streets. These rear-entrance facilities are imperative to reduce congestion on the street. The alley has become unpopular in residence districts. It was rarely kept in a sanitary condition and therefore was objectionable. The substitution of the motor car for the horse and the banishment of other domestic animals from the city have led to the abolishment of the stable and alley and have substituted the private drive direct from the street to the garage. Alleys are now rarely included in new plats and in many places existing alleys are being vacated.

City Planning.—This is the name given to the modern process of eradicating former faults in the city plan and preventing a repetition of them in the future. Rarely does it include the planning a new city in its entirety. *Zoning* is the first step in city planning. In this process the city is divided into areas in which the type of development is restricted. When such restrictions are established it is possible to design an adequate street layout and provide a feasible program of improvement.

Territory contiguous to a city, which may develop into urban property, exerts considerable influence on the scheme of zoning or planning within the city. In turn, its development is influenced by the city plan. This is the basis of the so-called *regional planning*. Rural highway authorities who are not giving due consideration to city or regional plans are making a sad mistake which future generations will have to correct.

CIRCULAR CURVES

Simple Curves.—A simple curve is the arc of a circle connecting two tangents. Since an infinite number of circles is available, the one most suitable for a given location is chosen to conform to the topography or to traffic needs. The mathematics of circular curves is treated in detail in any of the standard books on railway or highway curves and need not be considered here. Figure 14-10, however, is included for ready reference to the elements of a

D = degree of curve or the angle at the center subtended by an arc of 100 ft.

$R = \dfrac{5730}{D}$ (ft.)

$L = \dfrac{I}{D}$ (stations)

$T = R \tan \frac{1}{2}I$

$E = R \operatorname{exsec} \frac{1}{2}I = R(\sec \frac{1}{2}I - 1)$

$M = R \operatorname{vers} \frac{1}{2}I = R(1 - \cos \frac{1}{2}I)$

$L.C. = 2R \sin \frac{1}{2}I$

Sta. $T.C.$ = Sta. $P.I.$ − T

Sta. $C.T.$ = Sta. $T.C.$ + L

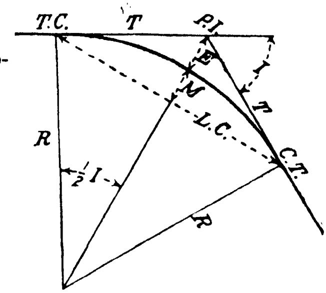


FIG. 14-10.—Simple curve.

simple curve. It is still customary to designate highway curves by their radii but for any radius over about 300 ft. the degree of curve is simpler to use.

In the days of horse-drawn traffic, radii were generally quite short. Right-angled turns frequently had only the curve permitted by the width of right-of-way. The higher speeds of motor traffic demanded flatter radius curves with the result that the radius for right-angled turns has been gradually increasing. The minimum radius should be not less than 500 ft. and in open territory about 2,000 ft. These correspond to degrees of curve of about 10 and 3 deg., respectively. Curves sharper than 3 deg. should be spiraled. Local conditions may necessitate shorter radii, in which case the curves become points of potential, if not actual, congestion and danger. They should, therefore, be adequately marked and made as safe as possible.

On city streets other conditions than traffic fix the radii. The street may be winding, in which case the curves may be quite long. At intersections the radius at curb corners will always be comparatively short but should be as long as conditions will permit.

Compound Curves.—A compound curve is a continuous curve in one direction composed of two or more simple curves placed

end to end with a common tangent at the junction. Compound curves are used where a simple curve will not fit the topography. The judicious use of compound curves will often greatly improve the alinement. Spirals should be used at the ends if the degrees of curve are more than 3 deg. and also between the two curves if their degrees of curve differ by more than 3 deg.

Reverse Curves.—A reverse curve is composed of two simple curves of opposite curvature placed end to end with a common tangent at the junction.

A reverse curve adds to steering difficulties, especially if sharp. If the curves are superelevated, the superelevation must change side and this can not be done suddenly. Since at least 100 ft. is desired to run out the superelevation, curves of opposite direction should have at least 200 ft. of tangent between them. If the curves are spiraled, the ends of the spirals may be made coincident since the spiral provides runoff for both curvature and superelevation.

Small Changes of Direction.—Whenever the alinement deflects through only a small angle, the curve is much foreshortened and appears much sharper to an approaching driver than it really is. To overcome this defect, both for the sake of appearance and for convenience to traffic, such curves should be made comparatively long. Just what the length should be is entirely a matter of judgment. Good practice indicates that for deflections less than 1 deg. the length may well be about 1,000 ft. As the change of direction increases, the length of curve may be decreased to about 500 ft. for intersection angles of 5 to 8 deg. With still larger angles the ordinary conditions controlling the choice of curve may govern, if it is always remembered that any curve appears foreshortened to an approaching driver. In no case, however, should the degree of curve be over 3 deg.

In areas under the rectangular land survey, direct offsets in otherwise straight alinement frequently occur at the correction lines. Such offsets are also found elsewhere. These offsets should be made with long reverse curves. On high-speed roads, even the smallest offsets should have a length of about 1,000 ft. and in no case should the degree of curve exceed 3 deg.

Broken-back Curves.—When two curves of the same direction are separated by a short tangent, the layout is termed a *broken-back curve.* Such curves add to steering difficulties and, in addition, are decidedly bad looking.

The maximum length of tangent in a broken-back curve is indefinite and is largely a matter of appearance. If the tangent is less than the normal superelevation runoff, the curve is unquestionably broken backed. It is undesirable to run out the superelevation and immediately run it in again on account of both appearance and the effect on traffic. Therefore, there should be a section of tangent, of indefinite length, without superelevation between the curves. Its length should be at least equal to the sum of two runoff distances or about 300 ft. This means that any tangent less than about 500 ft. should be considered a broken-back curve. If the layout is hidden by banks or woods, a shorter tangent may be permitted than in the case where the entire layout is visible.

Broken-back curves can frequently be eliminated by changing the radii of the curves or by shifting the tangents. They can always be corrected by compounding or by inserting spirals.

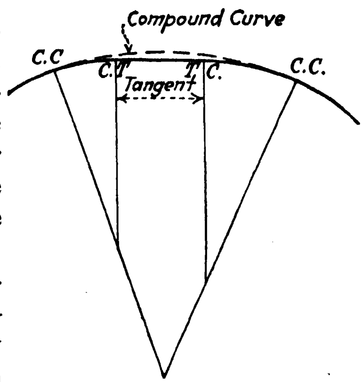


FIG. 14-11.—Broken-back curve eliminated by compounding.

Occasionally a curve may be necessary at the crossing of a railroad or another highway. The grade of the intersecting line may be such as to reduce, eliminate, or reverse the superelevation. In such a case a broken-back curve may be permissible in order to make the crossing on tangent. The total length of tangent should be enough to cross the intersecting right-of-way on tangent and provide reasonable runoff. Since there is an obvious reason for the tangent, the appearance does not greatly suffer. Such curves, however, can be greatly improved in appearance and riding qualities by the use of spirals even at the expense of sharpening the curvature.

Short-radius Curves.—Curves with radii of less than a tape length, as at curb corners, are most easily laid out on open ground by locating the center and then swinging the arc with the tape. If the center is inaccessible a parabola may be substituted for the circle and located as indicated below. The parabola, however, should be somewhat longer than the circle it replaces in order to give traffic the same turning radius, since the external

distance of a parabola is less than that of a circle with the same tangent lengths.

Parabolic Curves.—In Fig. 14-12 BA and AC are the two tangents with their $P.I.$ at A to be connected by the parabola having tangent distances T_1 and T_2, which need not be equal in length. These tangent distances are measured from A and the $T.C.$ and $C.T.$ located at B and C, respectively. The long chord BC is then lined in and its middle point A' located. The line AA' is then bisected and its middle point a, which is also the middle point of the curve, thus located. The other offsets, $Ff = Ll$, $Gg = Kk$, $Hh = Jj$, can now be computed since such offsets vary as the square of their distances from the point of tangency.

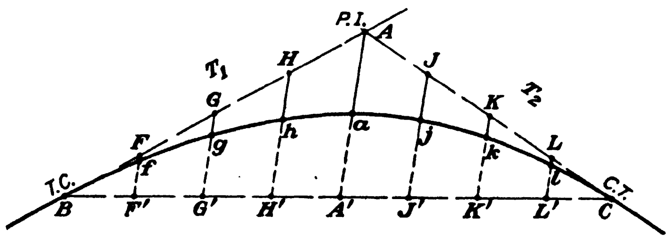


FIG. 14-12.—Parabolic curve.

These offsets are then measured from the tangents on lines parallel to AA'. For greater accuracy in alining these offsets the long chord may be divided into the same number of parts as the tangents and the offsets directed between corresponding points. If the long chord is inaccessible the length and direction of Aa can be computed from the triangle ABC and the curve located as before.

SPIRALS

The spiral is a curve of varying radius. It was developed in railroad work to ease the sudden change of motion at the ends of a curve and to permit the superelevation to be run out smoothly.

The spiral was introduced into highway work primarily to improve the appearance at the entrance to curves where the pavement was widened. The improved riding qualities as well as appearance have led to rather free use of the spiral even where the pavement is not widened. At speeds of 35 m. p. h. or more the improved riding qualities and ease of steering are noticeable on curves up to about 2,000-ft. radius. It is especially desirable on short-radius curves with maximum superelevation. It might

be even more freely employed were it not for a rather general but totally erroneous idea that the spiral is difficult to install. All curves sharper than 3 deg. should be spiraled.

Type of Curve.—Practically all transition spirals are based on the cubic parabola whose general equation is $y = mx^3$. The various spirals differ principally in the method of computing and unfortunately some of these methods are so cumbersome as to give some excuse for the belief that the spiral is difficult.

The easiest and most flexible spiral is that originally presented by A. N. Talbot.[1] It is based on the cubic parabola but its determining equation is

$$d = ks \tag{14-8}$$

in which d is the degree of curve at any point, s is the length from the point of beginning in stations, and k is the rate of change of

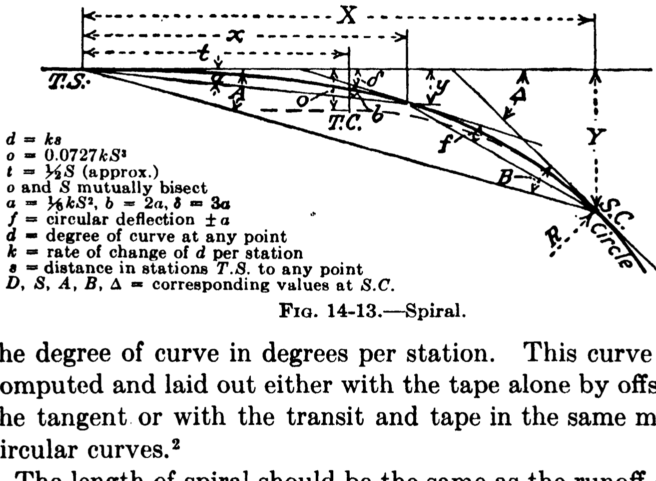


FIG. 14-13.—Spiral.

the degree of curve in degrees per station. This curve is easily computed and laid out either with the tape alone by offsets from the tangent or with the transit and tape in the same manner as circular curves.[2]

The length of spiral should be the same as the runoff of superelevation. An approximate length may be computed by Eq. 14-2, 14-3, or 14-4 as desired. The exact length of both spiral and runoff is then found from Eq. 14-8 using a simple value of k since this makes the spiral computations much easier.

Formulas.—Figure 14-13 is included merely for ready reference. It shows diagrammatically the transition spiral with the several

[1] For a detailed treatment of this spiral for both railroad and highway curves see "Route Surveying" by Pickels and Wiley, John Wiley & Sons, Inc., New York, 1930.

[2] The 10-*chord spiral* is the same curve on the ground but is much more difficult to compute and locate.

elements indicated. The lower case letters represent general values, while the capital letters represent the special case of the same functions as applied to the *S.C.* or junction of the spiral to circular curve. It must be remembered that mathematically a spiral is indefinite in length, while in practice it is cut off where its degree of curve is the same as the circular curve being used.

Spiraling Unwidened Curves.—When the pavement is not widened on the curve the spiral may be computed for the center line, the center line run in, and the form stakes set from it by offsets, care being taken to measure them radially. This makes the inner and outer edges concentric, and the spirals different in length. The inner and outer spirals may be made entirely different but there is no valid reason for doing this on unwidened curves.

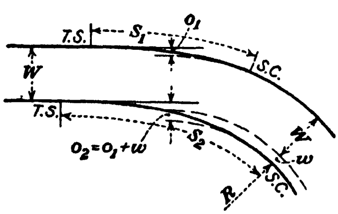


FIG. 14-14.—Spiraling a widened curve.

Spiraling Widened Curves.—When the pavement is widened the inner and outer spirals are unlike, owing to the widening.

The outer curve may be unspiraled. In this case the value of *o* for the inner spiral is the amount of the widening and *D* corresponds to the radius of the inner edge after the widening. The length of spiral *S* and *k* are computed from these values, and the spiral established.

In case the outer curve is also to be spiraled, a comparatively short spiral is chosen and installed on it. The value of *o* for the inner curve is then equal to the value of *o* for the outer curve plus the widening, from which the inner spiral is determined as before (see Fig. 14-14).

The superelevation is begun at the *T.S.* of the inner spiral and reaches the full amount at its *S.C.*

Problems

14-1. On an existing road system *B* is 12 miles east of *A* and *C* is 9 miles south of *B*. There are 500 cars per day between *A* and *B* only, 400 per day between *B* and *C* only, while 1,400 per day run between *A* and *C*. A paved road costs $30,000 per mile and a direct road from *A* to *C* 16 miles long can be obtained by acquiring new right-of-way 82.5 ft. wide at $300 per acre. Determine the economic location of the pavements.

14-2. In Prob. 14-1 assume that a gravel road suitable for 600 cars per day can be built for $6,000 per mile exclusive of right-of-way and is available in addition to pavement. What would be the economic layout?

14-3. A motor bus has a length from rear axle to front bumper of 30 ft. What widening would be required on a curve of 300-ft. radius? Compute by both equations and compare results.

14-4. What clearance is required for a sight distance of 600 ft. on a 10-deg. curve?

14-5. A curve extends 1,200 ft. through a cut 30 ft. deep. From the center line to the foot of the cut slope is 20 ft. and the slopes are 1:1. If the curve is daylighted by increasing the width by 10 ft. at an elevation 3.5 ft. above the roadway, how much additional excavation is required? If the daylighting takes the form of *ACD* in Fig. 14-9, how much more excavation is there?

14-6. Two tangents are to be connected by a parabola with tangents 200 ft. long. The distance from the *P.I.* to the middle of the long chord is found to be 24.0 ft. Compute the tangent offsets for locating points about 50 ft. apart.

14-7. Station of *P.I.* is 13 + 00, $I = 44° - 42'$, $D = 5° \ 00'$. Compute the functions of the curve as shown in Fig. 14-10.

14-8. The curve in Prob. 14-7 is to be symmetrically spiraled with a spiral of $k = 2$. Compute the new tangent distance and the functions A, B, Δ, X, and Y in Fig. 14-13.

CHAPTER 15

VERTICAL ALINEMENT

The position of a highway in the vertical plane is given by its *grade line.* The grade line is analogous to the center line in horizontal alinement and, like it, is made up of tangents connected by curves. The tangents are termed *straight grades,* while the curves are known as *vertical curves.* The grade line is located at any point by its *elevation* above some datum, and its direction is fixed by its slope with respect to the horizontal in *percent of grade,* or the rise in 100 ft. *Control points* or points through or near which the grade line must pass always exist.

Direct and Indirect Grades.—A *direct grade line* is straight between any two control points. If the center line is also straight between the same points, the roadway follows a straight line in space and is the shortest and steepest route between the points. If the horizontal alinement is indirect, the grade line may still be straight but will be longer and flatter. Direct grade lines of any considerable length are rarely obtainable, because they are very likely to require prohibitive cuts and fills. Consequently, the *indirect grade* line which dips into valleys and climbs over ridges is the normal one.

Maximum Grades.—The amount of friction between the drive wheels and the road surface combined with the amount of motive power which can be effectively applied to a given vehicle fixes the maximum grade which that vehicle can climb. The average passenger automobile, in low gear, can climb a grade of 25 to 30 percent on a dry, hard road surface, while the maximum grade for trucks is 20 to 25 percent. If the road surface is slippery the traction is insufficient and these grades cannot be climbed.

On descents it is necessary to maintain safe speeds, and occasionally to stop. With a dry, firm road surface, the foregoing grades can be descended safely provided they are not so long as to overheat the brakes. With slippery surfaces steep grades become exceedingly dangerous. In general, the safe descending grade is less than the possible maximum ascending grade.

On rural roads, grades approaching the foregoing maximums are occasionally found but only on outlying and little-used highways. Similarly, such grades may also be found on city streets but here again traffic is sparse and purely local and may be entirely discontinued under adverse weather conditions. On main roads and principal streets, the grades are kept well under these maximums and the tendency is to secure grades well below those which the average car can climb easily in high gear, for the sake of both safety and economy in operation.

Minimum Grades.—The minimum grade is fixed by drainage requirements. If a standard cross-section is to be maintained, there must be sufficient longitudinal slope to cause the water in the side ditches or gutters to flow. Open side ditches should have a minimum grade of about 0.1 percent, and 0.2 percent is better. City pavements should have a minimum grade of 0.2 to 0.3 percent in order that the gutters may drain quickly and completely. Except with the concrete gutter, it is almost impossible to make a gutter free from pockets on grades less than about 0.3 percent.

Long fills on rural roads may be laid level since the water drains away laterally. Short sections in cuts may also be made level, provided the ditches can be given a suitable slope without becoming so deep as to be dangerous. City pavements may be given level grades by placing inlets not more than about 200 ft. apart and sloping the gutters each way toward them. This results in a variable height of curb and adds a little to the cost and also to the difficulty of making the surface smooth riding.

Ruling Grades.—Ruling grades, as defined in railroad work, do not exist on highways. Each vehicle is self-contained and possesses sufficient power to carry it over any grade that is safe to travel. The grades, therefore, do not limit the load which a vehicle can carry. On the other hand, a grade so long and steep as to require the use of reduced gears may so retard traffic as to reduce or limit the traffic capacity of the road. The ruling grade of a highway may, therefore, be considered as that grade which requires all motor vehicles to change gears. Grades which do not require changing of gears are *minor grades* and exert little influence on the movement of traffic and the capacity of the road.

Grade Resistance.—On a slope there is a component of gravity acting down the incline which tends to retard a vehicle on the ascent and accelerate it on the descent. This force is commonly referred to as the *grade resistance.* From the principle of the

inclined plane, making the slight approximation that the horizontal and slope distances are equal, we have

$$R_g = 20G \tag{15-1}$$

where R_g is the grade resistance in pounds per ton of weight of the vehicle, and G is the percent of grade. Or stated in words, the *grade resistance is equal to* 20 *lb. per ton for each percent of grade.*

Road Resistance.—Every road offers resistance to a vehicle moving over it. This resistance is made up almost wholly of internal friction of the vehicle, resistance at the road surface, and wind resistance. Investigations[1] give the average value of the wind resistance on motor cars as

$$R_w = 0.0021AS^{1.9} \tag{15-2}$$

in which R_w is the total wind resistance in pounds, A is the projected area of the vehicle in square feet, and S is the speed in miles per hour.

Many experiments on road resistance indicate that friction and surface resistance do not sensibly change with the speed but that they are primarily functions of the weight of vehicle, the kind and condition of the road surface, and the size and type of tire. The actual conditions of highway traffic cover such an exceedingly wide range that only broad averages can be used in designing a road. Hence, for practical purposes, it is sufficient to combine these factors into a single item termed *road resistance* R_r and adopt values for some normal speed, say of about 40 m.p.h., for automobiles. For trucks the speed is less but the area subjected to wind pressure is larger; therefore the same values of R_r may be used for both trucks and automobiles.

Motor Efficiency.—The ordinary gasoline automobile motor does not work at a constant efficiency. The maximum efficiency is obtained when the load is such that practically full throttle opening is required at a speed of 35 to 40 m.p.h. The average American car uses only about one-third to one-half of its full power at a speed of 40 m.p.h. on first-class level roads. Its motor is, therefore, normally working at less than its maximum efficiency. As the road or grade resistance increases, more power is required and the motor efficiency rises to the point where

[1] Tractive Resistance as Related to Roadway Surfaces and Motor Vehicle Operation, *Bull.* 119, Iowa Eng. Expt. Sta., Ames, Iowa, 1934.

practically full throttle opening is required to maintain normal speed. Beyond this point the motor efficiency falls off rapidly. Trucks have the same characteristics but for speeds of 25 to 35 m.p.h.

These characteristics of variable efficiency have a certain theoretical effect on the economic design of vertical alinement. On the other hand, the improvements in motor design are tending toward both a higher and a more uniform efficiency. Consequently, the effect of variations in efficiency must not be overstressed, since future conditions may change. Present-day

TABLE 15-1.—AVERAGE ROAD RESISTANCES AT NORMAL SPEEDS WITH PNEUMATIC TIRES

Kind of surface	Road resistance, pounds per ton		
	Good condition	Average condition	Poor condition
Earth	70	90	150[1]
Sandclay	60	80	125
Oiled earth	50	70	100
Gravel	45	60	100
Macadam	45	60	100
Bituminous carpets and macadam	40	50	75
Sheet asphalt—asphalt concrete	40	45	70
Brick	35	40	70
Concrete	30	40	70

[1] Exclusive of deep mud which may more than double the resistance.

over-all efficiencies under average running conditions in high gear may be taken at 0.08 to 0.10 of the total energy in the fuel, and the maximum efficiencies at 0.14 to 0.16, although 0.20 may be reached under favorable conditions.

Gear Changes.—Gear changes are provided so that the tractive effort can be increased at the expense of road speed. Let it be assumed that an automobile has reached the steepest grade that it can climb satisfactorily in high gear. Gears are now changed to a lower ratio. To maintain the same car speed the motor must turn over faster by the actual change in gear ratios. The fuel consumption, however, does not change proportionately because the load on the motor is reduced. At the same time the efficiency of the motor changes somewhat, which has a secondary effect on the fuel consumption. With

certain minor losses in the gears neglected, the change in fuel consumption on the same grade due to changing gears may be estimated by the equation

$$f = \frac{ne_l}{e_h} \tag{15-3}$$

in which f is the ratio of fuel consumption in reduced gear to that in the high gear, n is the gear-box ratio of reduced gear to high gear, e_h is the efficiency of the motor on the grade in high gear, and e_l is the efficiency in reduced gear which, when gears are first changed, may be taken as the same as the normal efficiency on a level road. For automobiles n is about 2.0 for intermediate, and 3.5 for low gear, while for trucks the values are about 1.3, 2.0, and 3.0 for the three reduced gears. The tractive effort, or driving force at the wheels, is practically proportional to these values of n.

After gears have been changed on a given grade, the throttle can be reopened to give additional power to overcome still steeper grades or greater road resistance until again the motor is operating at full throttle. During this process the motor efficiency has been increasing from e_l to e_h and the fuel consumption ratio f has been increasing until it has reached the actual change in gear-box ratios, or n. Gears are now changed to the next lower ratio and the whole general process repeated.

Rise and Fall.—A given rise accompanied by an equal fall is termed *rise and fall*, because the work done against gravity on the rise is returned to the vehicle by gravity on the fall. If the descent is made without the use of brakes so that the full amount of potential energy is turned into useful work, and there are no other changes of efficiency, the rise and fall theoretically adds nothing to the cost of operation. If brakes are used on the descent, however, large losses of energy occur and therefore the cost of operation is increased. Changes in motor efficiency, the use of reduced gear, etc., also have greater or less influence on the cost of operation.

It is variously contended that (1) the cost of rise and fall is an unimportant element in highway operation and (2) that rise and fall does seriously affect the cost of operation and should be evaluated. The former is probably true on minor grades and the latter on steep grades where gears must be changed to make the ascent and brakes used to descend. In fact it is the evalua-

tion of some of these costs that makes it possible to estimate the permissible expenditure for grade reduction.

The complete evaluation of rise and fall is extremely difficult, if not impossible, on account of the large number of factors in the problem and the unknown manner in which they vary. Since fuel costs probably show the greatest change due to grades, an estimate of the cost of both ascents and descents, and hence of rise and fall, can be made by studying the fuel costs.

Cost on Minor Grades.—By assuming a grade on which the ascent is made in high gear and the descent without brakes it can be shown that

$$C_h = \frac{Wc}{F}(2{,}000h - R_rL_r)\left(\frac{1}{e_h} - \frac{1}{e_l}\right) \qquad (15\text{-}4)$$

in which C_h is the fuel cost of the rise and fall in dollars, W is the total weight of traffic in tons, c is the cost of fuel in dollars per gallon, F is the foot-pounds of energy in a gallon of fuel and may be taken as 90,000,000 for gasoline, h is the rise and fall in feet, R_r is the road resistance in pounds per ton, L_r is the distance covered by the rise and fall in feet, e_h is the motor efficiency of the ascent, and e_l is the efficiency on the descent.

Equation 15-4 shows that a change in motor efficiency is the only item that establishes a cost for the rise and fall, for, if e_h and e_l are equal, the equation reduces to zero. On the other hand, if e_h is less than e_l, as may happen if the climb is made at slow speed with a full throttle, C_h becomes a positive finite quantity and is the *increased fuel cost* due to rise and fall. Again, if e_h is more than e_l as may occur if the climb is made at the most favorable combination of speed and throttle opening, C_h becomes negative and is the *saving* due to the rise and fall. This phenomenon of an undulating grade line requiring less fuel than a level one has been observed in fuel tests on motor cars. It has already been pointed out, however, that the trend in motor design is toward a more uniform efficiency; hence it is not wise to attempt to insert undulations for the sake of fuel economy.

Cost on Steep Grades.—If the descent can be made without brakes while the rise requires a reduced gear, the fuel cost on the ascent must be multiplied by the ratio f, from which Eq. 15-4 becomes

$$C_h = \frac{Wc}{F}(2{,}000h - R_rL_r)\left(\frac{f}{e_h} - \frac{1}{e_l}\right) \qquad (15\text{-}5)$$

If brakes are used on the descent, there results a direct loss equal to the cost of the fuel that would be required to raise the vehicle to a height equal to the difference in height of the actual slope and another slope of the same length but on a grade which would permit the vehicle to coast freely, or

$$C_d = \frac{20WcL_d}{Fe}(G - G_d) \qquad (15\text{-}6)$$

where C_d is the additional cost of operation due to using the brakes, W, c, and F are the same as before, L_d is the length of the descent in feet, G is the percent of grade on the actual descent, G_d is the percent of grade which could be coasted freely, and e is the motor efficiency on the grade G_d. The value of C_d must be added to that of C_h from Eq. 15-5 to obtain the total fuel cost due to rise and fall when reduced gear is used on the ascent and brakes on the descent.

If the motor is used as a brake by closing the throttle and leaving the car in gear, there results a direct loss equal to the amount of fuel drawn through the motor at its average speed of rotation during deceleration less the amount required to idle the engine for the same length of time. The braking effect may be increased by using reduced gear but the fuel consumed is thereby multiplied by the factor n. Cutting the ignition adds the internal resistance of the motor at idling speed to braking effort. Opening the throttle with the ignition off increases the braking effort owing to higher compression in the cylinders but this also adds to the fuel used. Braking with the motor is, therefore, doubly expensive but may be justifiable on long steep grades on account of safety and to prevent damage to the brakes by overheating.

Distance Equivalent.—It is sometimes desired to know the distance equivalent, or distance on a level road in which the cost of fuel would be the same as that due to rise and fall. This may be estimated by finding the general expression for fuel costs on the level road and equating it to the costs of rise and fall.

For minor grades L_h the distance equivalent is given by the equation

$$L_h = (L_o - L_r)\left(\frac{e_l}{e_h} - 1\right) \qquad (15\text{-}7)$$

in which L_o is the distance on the level required to absorb the

potential energy due to a height h and is equal to $\frac{2{,}000\,h}{R_r}$, and the other terms are as before.

If reduced gear is used on the ascent but brakes are not required on the descent,

$$L_h = (L_g - L_r)\left(\frac{fe_l}{e_h} - 1\right) \tag{15-8}$$

If reduced gear is used on the ascent and brakes on the descent then

$$L_h = (L_g - L_r)\left(\frac{fe_l}{e_h} - 1\right) + \frac{20}{R_r}(L_g - L_r)(G - G_d) \tag{15-9}$$

Inertia Grades.—The maximum economic ascending grade is one which permits the vehicle to climb without shifting gears and within the speed range of high motor efficiency. If the grade is not too long, and if the alinement is favorable so that a "run can be made for the hill" or the acceleration from a previous descent utilized, then the grade can be partially climbed by inertia.

By deriving expressions for the total work to be done in climbing the grade and for the total energy available including 5 percent of the kinetic energy of translation as the kinetic energy of rotating parts, equating, and reducing, it can be shown that

$$G_a = \frac{3.5}{L_a}(S_b^2 - S_t^2) + \frac{T - R_r}{20} \tag{15-10}$$

where G_a is the economic maximum ascending grade in percent, L_a is the length of the grade in feet, S_b and S_t are the respective speeds at bottom and top in miles per hour, T is the average tractive effort of the drive wheels on the road, and R_r is the road resistance in pounds per ton.

If the grade is long the effect of inertia is practically lost, and if it is necessary to start on the grade the term for inertia disappears from the equation, from which in both cases the maximum economic grade becomes

$$G_a = \frac{T - R_r}{20} \tag{15-11}$$

This equation should be used on all grades over about 2,000 ft. long, and elsewhere where conditions of alinement, structures, etc., do not permit the utilization of inertia.

Descents.—The economical maximum minus grade is that which permits a vehicle to descend at a safe speed without the use of brakes.

Following the method used for ascending grades it can be shown that the economic descending grade is

$$G_d = \frac{3.5}{L_d}(S_b^2 - S_t^2) + \frac{R_r}{20} \tag{15-12}$$

If the same speeds are permissible in both directions then by equating G_a and G_d from Eqs. 15-10 and 15-12 and reducing, $T = 2R_r$, which shows that whenever R_r is less than $\frac{1}{2}T$ the economic descending grade is less than the economic ascending grade.

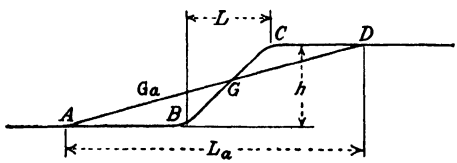


FIG. 15-1.—Grade reduction.

Reducing Grades.—In Fig. 15-1 the existing grade G on the line BC is greater than G_a and is to be reduced to that value by cutting and filling to the line AD.

For Ascending Traffic.—Since reduced gear is required, the fuel cost on the existing grade is

$$\frac{Wc}{Fe_l}(L_a - L)R_r + \frac{Wc}{Fe_l}LR_rf + \frac{Wc}{Fe_l}2{,}000hf$$

The fuel cost on the revised grade is

$$\frac{Wc}{Fe_h}L_aRr + \frac{Wc}{Fe_h}2{,}000h$$

The saving is then

$$S_a = \frac{Wc}{F}\left[\frac{(L_a - L)R_r + LR_rf + 2{,}000hf}{e_l} - \frac{L_aR_r + 2{,}000h}{e_h}\right] \tag{15-13}$$

or

$$S_a = \frac{Wc}{F}\left[\frac{(L_a - L)R_r + fL(R_r + 20G)}{e_l} - \frac{L_a(R_r + 20G_a)}{e_h}\right] \tag{15-14}$$

Equation 15-13 is suitable for use when the grade is to be reduced without reducing the height h. Equation 15-14 may also be used in this case but is especially applicable when the height is to be reduced at the same time.

If W is the total annual traffic in tons ascending the grade, then S_a is the annual saving.

For Descending Traffic.—If brakes must be used on a descent the saving due to reducing the grade to G_a is, by analogy with Eq. 15-6

$$S_d = \frac{20WcL}{F}\left(\frac{Gf}{e_l} - \frac{G_a}{e_h}\right) \tag{15-15}$$

The total annual saving

$$S = S_a + S_d$$

The *limit* of the total amount P which can economically be expended to reduce the grade is the sum obtained by capitalizing S at the current rate of interest r, or

$$P = \frac{S}{r} \tag{15-16}$$

Normally, however, it is desired to pay off the debt in a limited time. P in this case is usually taken as the present value of the annuity S for N years or

$$P = S\left(\frac{1 - (1 + r)^{-N}}{r}\right) \tag{15-17}$$

Since public bodies are almost universally restricted to the use of serial bonds in financing public improvements, the conservative way of estimating the permissible expenditure is on the basis of the amount of serial bonds on which S will pay the maximum installment of principal and interest. This is given by the equation

$$P = \frac{S}{\frac{1}{N} + r} \tag{15-18}$$

If the total cost of revising the grade due to right-of-way, earthwork, and structures is equal to or less than P, it is economical to reduce the grade, provided the total distance is not increased.

If the total distance is increased, the added cost of operation S_l due to the added distance must be computed and must be subtracted from $S_a + S_d$ to determine the value of S.

Reducing Descending Grades.—If the grade is reduced below G_a, there is no additional saving to ascending traffic. In fact, there may be a slight increase in cost due to reduced motor efficiency but this may be neglected. The saving effected by reducing G_a to G_d is, therefore, due to utilizing the energy absorbed by the brakes on the steeper grade. By analogy with Eq. 15-13, the saving by coasting is

$$S_c = \frac{20WL_a c}{F}\left(\frac{G_a}{e_h} - \frac{G_d}{e_l}\right) \tag{15-19}$$

The sum this saving will provide can be computed from Eq. 15-17 or Eq. 15-18, and if more than the cost of necessary construction it will be economical to reduce the grade to the maximum economic descending grade.

Time.—Attempts have been made to evaluate the time lost due to decreased speed on a grade. *Time is of no value unless it can be utilized.* It is therefore unimportant to either commercial or pleasure vehicles whether a grade requires a few seconds more or less. No one can calculate his time schedule so closely.

If the grade is sufficiently long and there are a sufficient number of such grades on a given route to accumulate a *usable amount of time,* then it may be logical to attempt to evaluate it. To do this, the number of vehicles *which can profit by the saving* must be estimated and the total time lost per year computed. A money value of the time must then be assumed, from which the annual saving and the allowable expenditure may be estimated.

Grades for Horse-drawn Traffic.—A horse can exert a normal continuous tractive effort for a reasonable working period equal to about 0.1 his weight. This force is available to overcome road resistance to the vehicle and grade resistance to horse and vehicle. By knowing the weight of the horse and the road resistance in pounds per ton, the load which he can pull up a given grade, or the grade possible for a given load, can be easily computed by equating the tractive effort and the total resistance.

A horse can, for a short time, exert a force up to 0.5 his weight but fatigues quickly. For very short distances with good footing his pull may even equal his weight. These characteristics,

however, cannot be used in establishing long road grades but they make it possible to pull normal loads up short steep stretches such as private drives, etc.

Example.—Assume a team weighing 3,000 lb. It is desired to know what load it can pull up a 4 percent grade, on road having tractive resistance of 40 lb. per ton, by exerting normal pull. The total available tractive effort is $0.1 \times 3{,}000 = 300$ lb. The effort required to raise the team up the grade is $1\frac{1}{2} \times 20 \times 4 = 120$ lb. The net effort to apply to the load is $300 - 120 = 180$ lb., the resistance to the load is $4 \times 20 + 40 = 120$ lb. per ton, from which the load is $180 \div 120 = 1\frac{1}{2}$ tons. By doubling their effort the load would be $\dfrac{0.2 \times 3{,}000 - 120}{120}$ or 4 tons.

If long, steep grades for horse traffic must be used, *rest platforms*, at least the length of load and team, should be provided at

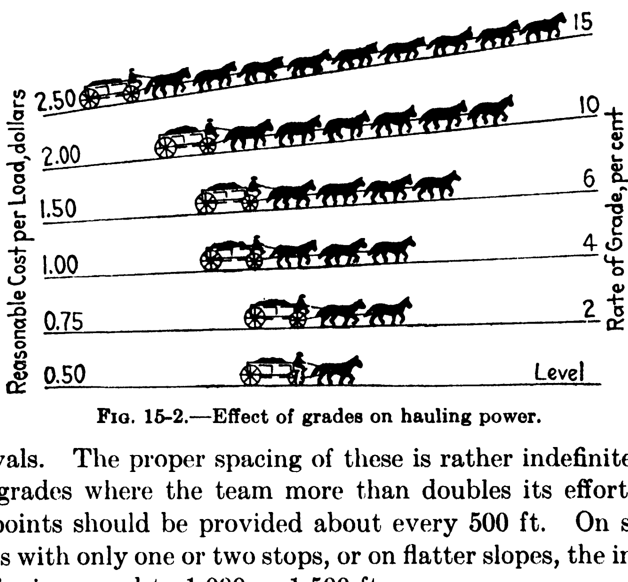


FIG. 15-2.—Effect of grades on hauling power.

intervals. The proper spacing of these is rather indefinite. On long grades where the team more than doubles its efforts such rest points should be provided about every 500 ft. On shorter grades with only one or two stops, or on flatter slopes, the interval may be increased to 1,000 or 1,500 ft.

On descents the team can exert a certain back pull which aids in controlling the vehicle. It is usually assumed that a team can handle a full load on a grade of $1\frac{1}{2}$ to 2 times the angle of repose for the particular surface, without brakes and up to 15 to 20 percent with the use of brakes.

LAYING A RURAL GRADE

Where the alinement is definite, a profile of the center line and cross-sections at intervals of 100 ft. are obtained. Sufficient

readings must be taken to insure an accurate plat of the cross-section, well beyond the limits of the probable cut or fill. Where the alinement is not definite, as on a relocation, topographic data sufficient to enable an estimate of the required cut and fill are necessary. The elevation of high water in all streams, the top of rail at railroad crossings, and of existing pavements to be joined or crossed must be determined accurately. Likewise the elevation and location of farm entrances, buildings, and other improvements which may affect the grade line are required.

Control Points.—The control points are platted on the profile sheet and become the starting points for laying the grade line. Absolute control points such as grade crossings with railways, existing road and streets are so indicated. Approximate control points such as high water in streams, rail elevation at over or under crossings, and adjacent improvements are platted and noted.

If the new grade starts at the end of an existing improved road, the grade of the existing road for 300 or 400 ft. from the end must be obtained so that the new grade will continue from it without break. If the road is to begin or end on an unimproved section, the grade line must be projected beyond the actual end several hundred feet, but preferably to the next control point, so as to avoid the possibility of bad conditions when the improvement is extended.

Balancing Earthwork.—A straight grade line between control points is rarely obtainable but it is sometimes convenient to plat it as a guide. Often it will serve to show that undulations are not necessary. In order to reduce cost, it is desirable to keep the total earthwork as low as is consistent with other requirements and also to balance the earthwork so that the cuts will make the fills within economic haulage distances and thus reduce the cost.

The desire to reduce or balance earthwork should, however, never be permitted to interfere with the establishment of a grade line of good appearance or of correct design for economic operation. Earthwork should control the grade line only after all other conditions are fulfilled. Furthermore, it should be remembered that there are many possible grade lines of low and balanced earthwork. Therefore, the first one found is not the only one possible, and if it does not satisfy the other requirements the designer should *try again* until one is found.

The methods of computing earthwork, balancing cut and fill, and estimating haul are outlined in Chap. 6. In making trial grade lines, the vertical curves should always be spotted on the profile, thus avoiding any errors due to not properly considering them. The vertical curves should always be as long as conditions will permit. The minimum length should be used only in emergency.

Vertical and Horizontal Curves.—The tentative grade line should be compared with the proposed center line in order to ascertain and adjust if necessary the relative positions of vertical and horizontal curves. If a horizontal curve having considerable superelevation ends on a vertical curve, the change of grade combined with the superelevation and runoff may result in very bad appearance and possibly poor riding qualities. This should be avoided by shifting either the grade line or the center line or by using very flat curves.

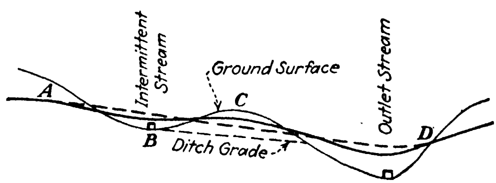


FIG. 15-3.—Unnecessary minor undulation in grade line.

Grades and Relocation.—Steep grades should next be studied with the view to reducing them to economic limits as previously outlined in this chapter. In this connection different grades and different alinements should be investigated and a comparison made of the economic costs, including first cost and operation, of the several possible routes and grades. It is frequently possible by relocation to secure not only better alinement but an improved grade line as well.

Drainage.—The grade line must be carefully studied in relation to drainage. Frequently small changes in grade may greatly facilitate the rapid and complete removal of surface water. It is vastly more important that the surface be promptly and effectively drained and protected from flood than that the earthwork balance or be a minimum. Money spent in improving drainage is always well spent.

Figure 15-3 shows a condition often seen. In order to save earthwork, the undulating grade *ABCD* is laid and the culvert at

B installed to carry the surface water across. The grade *AD* not only looks better and rides better but may actually cost less because the culvert can be eliminated and the water drained directly to the outlet stream. If the stream at *B* is flowing, it should, of course, have a culvert but even then the grade *AD* is preferable even at some extra cost.

Stream Crossings.—Grade elevations at stream crossings are most frequently governed by high-water level. Bridges must have sufficient clearance above the highest known high water to permit the passage of drift or ice. If the drainage area is undeveloped, extra clearance is advisable because greater floods may be expected when it is developed. The depth of the floor system added to the clearance fixes the minimum elevation of the grade line.

Embankments across flood plains should have a minimum height of 4 ft. above highest known flood level. At best 4 ft. is none too much and, if the stream is not well known, a greater height should be used. If in time of flood a long wide stretch of open water touches the embankment, the height above the water should be greater to be safe against wave action. Riprap may be necessary to protect the bank.

Navigable streams require considerable clearance at bridges. The requirements for such bridges are fixed by the U. S. War Department. Drawbridges may be cheaper to build than fixed spans and approaches at suitable elevations but the delay to traffic when the bridge is open is always inconvenient, often expensive, and frequently dangerous. The high level bridge should always be employed if possible, especially on primary roads.

Railroad Grade Crossings.—Railroad grade crossings are absolute control points on the grade line. Every effort must be made to reduce the danger to a minimum and a proper grade approach is an important element.

If the crossing is in a cut where clear view of the railroad for a reasonable distance each way is impossible, a study should be made to determine whether or not a more favorable crossing can be obtained by relocation. If relocation is not permissible the grade line must be so established as to permit the vehicle to be kept under control on the descent and to stop before reaching the tracks. The bank should be daylighted as much as possible

With the railroad on a fill the grade line must rise to it. The approaches should be on easy grades with a nearly level section on which the vehicle may stop on each side of the track. It is not necessary for the control of the vehicle that this space be exactly

FIG. 15-4.—A safe crossing.

FIG. 15-5.—A dangerous crossing.

level, while good appearance demands that it have some camber. If level, it will appear to have a depression at the track.

Figures 15-6 and 15-7 show recommended approaches to tracks in cut and on fill.

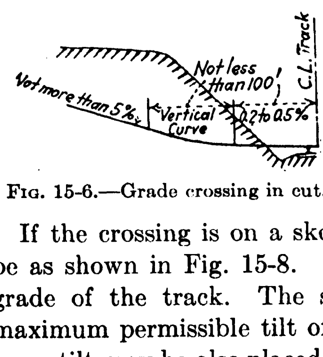


FIG. 15-6.—Grade crossing in cut.

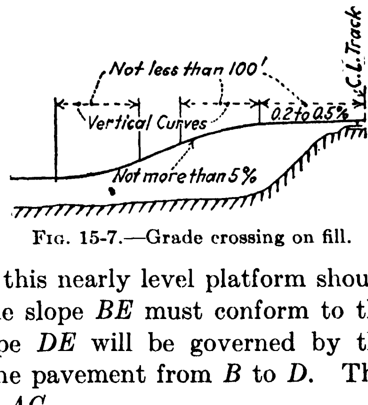


FIG. 15-7.—Grade crossing on fill.

If the crossing is on a skew this nearly level platform should be as shown in Fig. 15-8. The slope *BE* must conform to the grade of the track. The slope *DE* will be governed by the maximum permissible tilt of the pavement from *B* to *D*. This same tilt may be also placed on *AC* or may be somewhat reduced, but *AC* should not be made level or there will appear to be a hump at *C*. The slopes *AB* and *CD* should be 0.2 to 0.5 percent and should be at least 100 ft. long on rural roads. On city streets it may be necessary to make *AB* very short, but the slopes should be kept on the same gradients to avoid a bad break of grade at the track.

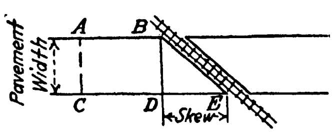


FIG. 15-8.—Grades at skew crossing.

If the railroad is on a curve the grade of the highway for a short distance is fixed by the superelevation of the track. Vertical curves as long as conditions permit, but not less than 50 ft., should be used to introduce this section of grade. The effect of skew is then worked out as before, special care being taken to secure good appearance and good riding qualities. The resulting grade line should be checked against the horizontal alinement as previously suggested.

Undercrossings.—When the highway goes under the railway by means of an *underpass* or *subway*, the difference in grade

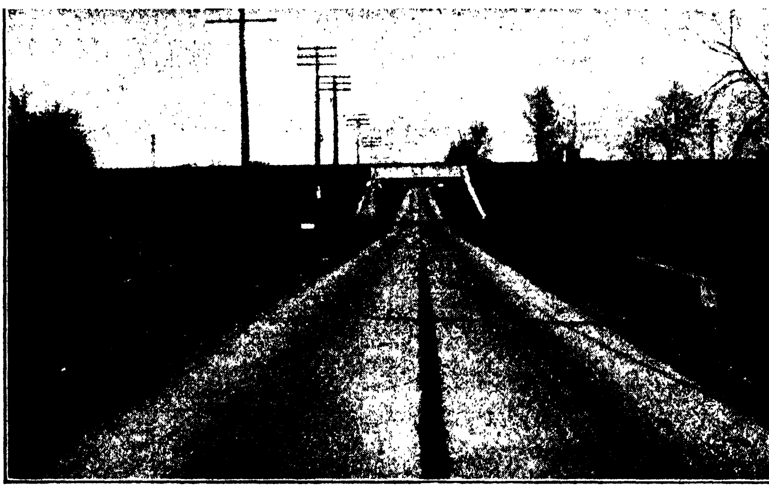


FIG. 15-9.—An underpass or subway. Note the absence of center piers.

elevation is equal to the clearance required for the road plus the depth of floor system of the bridge. The minimum highway clearance is 12 ft. Something in excess of this is always desirable; hence 14 ft. is the desirable minimum. The depth of floor system will depend on the span and the type of construction. Center piers should never be permitted on a rural road or on streets if it is possible to omit them. With a ballasted floor the distance from clearance line to top of rail is likely to be about 4 ft.; therefore the minimum distance between grade lines is 16 to 18 ft.

The approach grades should be not more than 5 percent, and the vertical curves of ample length. There is a tendency on the part of the railroads, where they control the approaches, to use

unduly short curves. It is better to steepen the grade somewhat and use longer curves.

Overhead Crossings.—An overhead crossing requires greater separation of grade lines. Many states fix by law the minimum clearance over the rails and this requirement should always be learned before laying the grade line. The average is about 22 ft. Allowing 2 ft. for floor depth of the highway bridge the minimum distance between grades is about 24 ft.

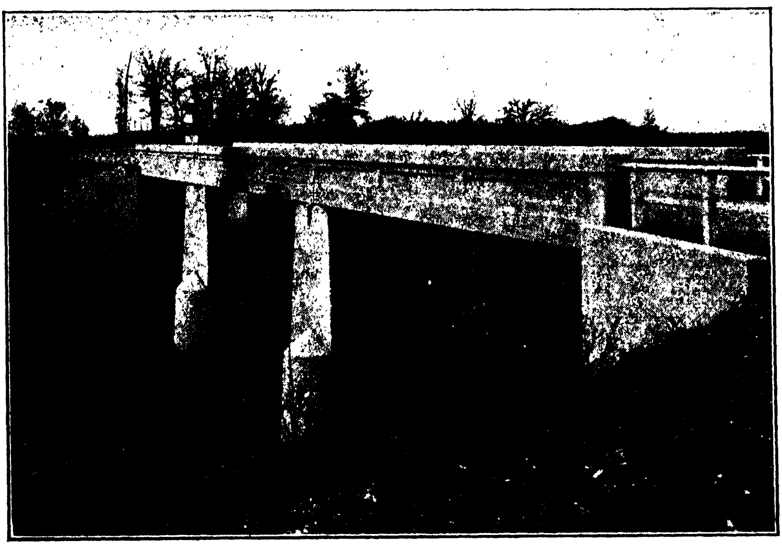


FIG. 15-10.—An overhead crossing.

The approach grades should again be not more than 5 percent and the vertical curves not less than 200 ft. The grade line over the structure should give ample sight distance and also a pleasing effect of camber.

Minor Undulations.—There is frequent controversy over the question whether to follow the minor variations in the ground surface or to make a *railroad grade.* From the standpoint of economic operation there is little to be said. The undulating grade is more inconvenient to lay out and construct, while the saving in earthwork is often largely imaginary. From the standpoint of appearance the eradication of minor undulation is always desirable. The grade line of long tangents and sweeping vertical curves, following the major ground slopes but eliminat-

ing minor undulations, is always the most pleasing in appearance and the easiest to drive over, and probably the safest.

Esthetics.—The fact must not be overlooked that everything on the highway is visible to the traveler, while on the railway he obtains only a restricted view. Highways therefore demand more in the way of esthetic treatment. After all of the above-mentioned conditions which affect the grade have been studied and a tentative grade line established, it must be critically examined for appearance. This requires a large amount of

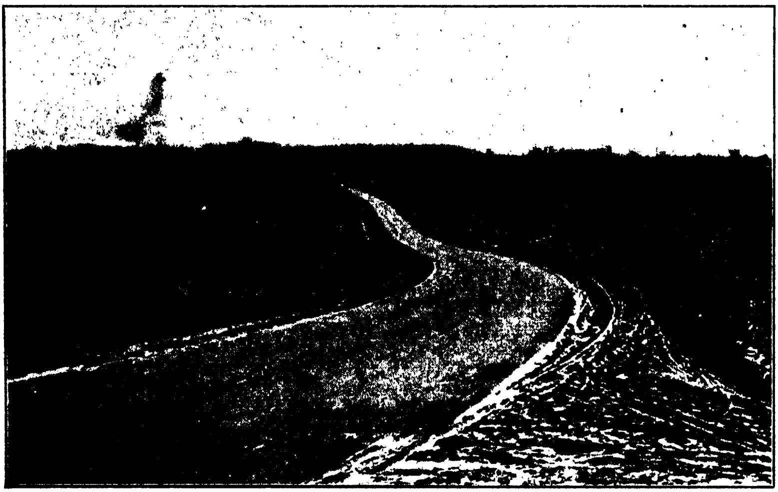


FIG. 15-11.—A minor undulation in the grade line which gives the appearance of crooked alinement.

engineering imagination. The engineer must be able to see distinctly a mental picture of the finished road. If he cannot do this he is not competent to make the design. There is a saying, "If it looks right it may be wrong, but if it looks wrong it can't be right." In no place is this more applicable than to grade lines. The final test of a good grade line is its appearance. It is worth paying for a few yards of earthwork to have the job look well.

Grade through Municipalities.—Whenever a highway is paved through a municipality the grade should be established as for a city street. The pavement width may be the same as outside the village and side ditches may be employed but these should be so made that the road can be transformed into a paved street of proper cross-section. The state or county has no conceivable

right to disfigure any village or city street by using an improper grade line to save or balance earthwork as is all too frequently done. The most common fault is to set the grade too high so that when the curbs are added they are above the sidewalks or adjacent property. The mistake is also made of following undulations that should be eliminated. A still further blunder is to follow the old fallacy that intersections should be level. If the proper grade increases the cost the difference should be paid and not be made an excuse to build the road incorrectly.

ESTABLISHING STREET GRADE

The general data required are a profile of the center line and each property line or sidewalk, the elevations of the ends of curbs and pavements at all intersecting paved streets, the elevation top of rail at railroad crossings and of street railway tracks, high water in streams, the location and elevation of any special improvement on adjoining property that might influence the grade, an approximate profile of intersecting unpaved streets for at least a block each way, and information as to alleys, existing drainage facilities, public utilities, etc.

Normal Section.—The normal section is all in cut as shown in Fig. 5-3. Balancing cut and fill therefore does not concern the problem except in rare cases. In general, the excavated material must be wasted elsewhere than on the right-of-way; hence the cost is likely to be high. On the other hand, the grade line will more nearly follow the ground surface and heavy cuts are not probable. Sometimes long stretches of street are all on fill. Here again balancing earthwork is unimportant. The final section is the same as if in cut.

Parking Slopes.—On business streets, where the entire width between curb and property may be covered with sidewalks, the transverse slope of the sidewalk should be about 1/4 in. per foot, or 2 percent. Some variation in this slope may be necessary but if possible it should not exceed 3/8 in. to the foot on account of comfort and safety to the pedestrian and be not less than about 1/16 in. per foot for drainage.

On a residence street the minimum slope of a grass strip is again about 2 percent. The maximum slope, however, is governed by the safe slope for private drives. Since these drives are always short they can be operated by inertia or in low gear and may safely have a slope of 20 to 30 percent from the gutter

to sidewalk. The parking slope is less than that of the driveway by the height of the curb. Care must be taken that the break of grade in the driveway at the sidewalk is not so great as to permit the running boards or other underparts of a car to drag on the edge of the walk.

Tilting.—When a street lies on a side hill so that one side is considerably higher than the other, the appearance can be improved and some of the difference of elevation taken up by tilting the pavement. For good appearance the maximum amount of tilting is about one-fiftieth of the width. For steep side hills the tilting may be greater than this if it seems justifiable. It is often necessary to tilt pavements, at least for a short distance, at intersections to provide for the grade of the intersecting street.

The effect of tilting is to throw the high point of the crown toward the side instead of in the middle, causing an unequal division of the surface water between the two gutters. If the tilting is equal to or greater than four times the crown, all of the water will drain to the low side. This must be considered in providing drainage facilities. Tilting is accomplished by placing the curbs at different elevation and striking the crown in the regular manner from the curbs. It is therefore quite easy to vary the tilting from point to point as may be desirable.

Curb Grade vs. Center-line Grade.—The elevation of the top of the curb is the important item in a street pavement grade. The curb grade is therefore the easiest to establish, most convenient during construction, and provides best for tilting. The center-line grade, however, is frequently shown on plans for convenience in legal proceedings incident to the making of a special assessment.

The curb grades should always be first established. If the pavement is to be tilted a grade line should be laid for each curb. The center-line grade may then be worked out from the mean of the curb grades. Some engineers show the center-line grades and in addition give the elevations of the curbs. This is the best method.

Earthwork.—As previously stated a street pavement is normally in cut; therefore cut and fill cannot be balanced. It is desirable to keep the amount of excavation a minimum but this should never be done at the sacrifice of appearance or convenience. The total earthwork is only a small part of the cost of a pave-

ment; therefore a few cubic yards more or less exert little influence on the cost. Methods of computing earthwork are given in Chap. 6.

Parkings should always be graded as part of the paving project. Many cities excavate for the pavement only and leave the parkings to be cared for by the property owners as they see fit. The result is that the space between sidewalk and curb is rough and irregular and often unsightly. It will cost the property owner more, in personal or hired labor, to finish the parkings himself than it would to have his assessment increased enough to pay for having the work done by the organized outfit of the contractor. At least the rough grading should always be done by the contractor. He may also be required to finish the surface, and in some cases he has been called on to plant the grass seed.

Beginning and Ending.—If the project is detached, it may be begun at either end. The survey and the study of the grade line should extend at least a block beyond the limits of the improvement at each end, in order that future extensions can be properly anticipated.

If the project connects with an existing pavement at one end, the survey and plans should begin at the established improvement and extend away from it. The survey should be carried sufficiently beyond the proposed end so that the plans are properly made to permit another extension later. If it connects with an existing pavement at both ends, it may begin at either end as is most convenient.

Intersections.—If the cross streets are paved, they become absolute control points. The grades of the curbs and of the center line of the given street must be adjusted to conform to the existing pavements. If, however, the turnout wings of an existing pavement are not of the required dimensions for the new work, or their grades have been badly laid, they should be torn out and relaid to proper grade and size as part of the new work.

If the cross streets are unpaved they are approximate control points and the problem includes establishing a section of grade line for each of the cross streets as well as the grade line of the given street. If the grades are all flat, say less than about 2.0 percent, the grade lines on the given street may be carried through the intersection. The grade for the cross street is then provided by raising or lowering the ends of the turnout wings to agree with an approximate grade.

For example, in Fig. 15-12 the elevations of B, C, O, and P are established in accordance with the grade of the given street. The elevation of D is computed from that of C to conform with an estimated grade on the cross street. In the same way the elevation of N is determined from that of O. This, however, would tilt the cross street from D to N the same amount as the slope from C to O. If this tilt is not wanted it can be partially or entirely eliminated by raising N the required amount. The grades for the other wing are determined in a similar manner. The grade lines of the cross street will show small breaks of grade at the curb lines of the given street, and possibly also later at the property lines when the cross street is paved, but these will be indistinguishable either in riding qualities or in appearance.

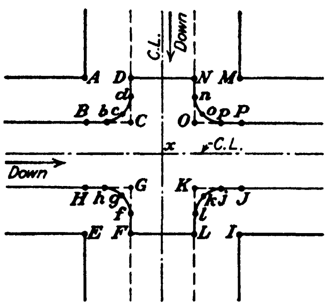


FIG. 15-12.—Corner grades at street intersections.

With slopes greater than about 2.0 percent the laying of grades for an intersection becomes more complicated. No definite rules can be laid down for doing this. It is a matter of judgment to set the grade lines in such a manner as to fit the conditions, accommodate traffic, provide drainage, and be good in appearance. The problem, therefore, largely resolves itself into establishing separate grade lines for each curb on both streets.

With reference again to Fig. 15-12, the first step is to determine the elevations of the property corners A, E, I, and M, and the slopes of property lines each way from them. These may be fixed by existing improvements in which case the curb grades are fixed within comparatively narrow limits especially on business streets. If the property is undeveloped, the problem is simpler because both the curb grade and the property grade can be shifted. Taking the northwest corner as an example, elevations for B and D are established from A so that water will normally flow away from the property. The cross slope from A to B or D is governed by the permissible slope of sidewalk or parking. Tentative curb grade lines are now run through B and D so as to intersect at C, and these grade lines carried back through their respective blocks. These grade lines probably will not be straight. Small breaks of grade may be permitted at the

property lines, *i.e.*, at *B* and *D*, but vertical curves should normally be used.

In the same manner tentative grades at the other three corners and through the corresponding blocks are established. The given street will now be tilted to the south, the cross street to the east, and the intersection to the southeast. The layout must now be critically examined to determine whether any of these cross slopes are excessive, or if there are any conditions that would adversely affect appearance, drainage, and riding qualities. If such are found, the corresponding grade line should be revised. The center-line grade is balanced in from the curb grades. Skew intersections are worked out in the same general way.

Curb Corners.—The curb corners at intersections are curved to such radii as conditions will permit, preferably not less than 12 to 15 ft. The laying of the grade around these turns is part of the problem of the intersection, and the criteria of a good job on this part are good appearance and good drainage.

At the northwest corner in Fig. 15-12 the elevations of *B*, *C*, and *D* have been established as previously outlined. From these the elevations of *b* and *d* can be determined. An elevation for *c* is now wanted. From the elevations of *b* and *d*, and the known grades, two elevations of *c* can be computed. These two elevations will be the same only when the two grades are equal. If they are not the same, an adjusted elevation of *c* is selected which may be but is not necessarily the mean of the two, but *c* must always be lower than *b* and *d*, if an inlet is to be placed on the apex of the corner. If the inlets are to be placed ahead of *B* and *D*, the elevation of *c* may be raised in order to gain backslope in the gutters from the apex to the inlets.

At the northeast and southwest corners the slope is continuous around the curve but must be adjusted from the known grades. Intercepting inlets may be used but these do not affect the grades. At the southeast corner the grade falls in both directions; hence *k* must be the highest point and its elevation is adjusted from those of *j*, *K*, and *l* in a manner similar to the determination of *c* from *b*, *d*, and *C*.

The mistake is often made of using a uniform slope around the corners. This is not objectionable for the elevation of *g* and *o* but is unsatisfactory at *c* and *k* on account of appearance and sometimes because of defective drainage.

Appearance.—Within the limits just outlined, the grade line is established with respect to the topography and the development of the adjoining property. If the property is built up, the grade line must be adjusted to it. If the land is unoccupied, there is greater freedom in establishing the grade and it becomes the keynote of later development. Streets are frequently paved as much for appearance as for any other reason and therefore appearance is one of the primary considerations in laying the grade. This phase must never be neglected and considerable money may justifiably be spent to secure good appearance.

Straight Grades.—That breaks of grade should be made only at streets or alleys is a fallacy that has persisted from the early days of paving. There is no conceivable reason why grade changes should not be put wherever the good of the improvement demands. Grade changes in a block in no way interfere with good drainage but, in case of a sag, the low point comes in the middle of the block and suitable drainage facilities must be provided. A grade line made up of tangents between intersections is generally unsightly and often disagreeable to traffic except where the grades are very light, say under 1 to 1.5 percent.

Vertical Curves.—Vertical curves should be used freely and always of ample length. The minimum length is rarely less than 50 ft. and more frequently lengths of 100 to 300 ft. are possible. The length should be chosen which fits the topography the best. A short vertical curve at a crest may bring the curbs too near the elevation of the sidewalks and give a bad appearance. There is no valid objection to carrying vertical curves through intersections except that sometimes it is difficult to secure good appearance because the turnout wings tend to give a broken-backed-curve effect at the curb lines. Vertical curves should be used to eliminate breaks of grade at railroad crossings as outlined for rural roads and also at street intersections as indicated in Fig. 15-14.

Drainage.—Drainage must be given due consideration. This will limit the minimum grade or create the necessity for curb of variable height. Minor undulations in the grade line may often be eliminated to improve drainage. Suitable grades leading to an adequate number of properly located and efficient inlets to a well-designed system of storm drains are essential to effective drainage of city streets. The design of storm drains is outlined in Chap. 5.

Common Faults.—Figure 15-13, sketched from an actual pavement, illustrates two common faults, both of which are due to a misconception of the worth of a few yards of excavation.

The first fault is that the curb grade approaches the sidewalk elevation too closely at the crest, thus giving the pavement the appearance of coming out of the ground. This should always be

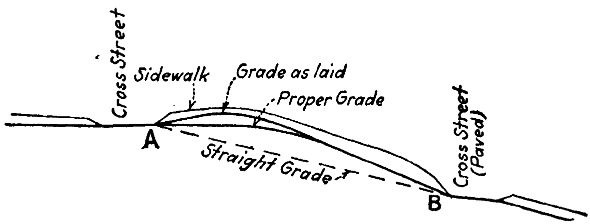


FIG. 15-13.—Faulty street grade.

avoided. The slope between curb and sidewalk should be as uniform as possible in each block, with a tendency toward becoming greater rather than less at a crest.

The second fault is the hump in the grade. It forms an adverse slope in an otherwise ascending grade line and is unsightly. At night a blind space is formed to the left of A. In the particular instance from which this is taken the hump necessitated an additional inlet and connection at A costing about \$70. The additional earthwork to remove the hump would have cost about \$140; therefore the net additional cost of making a proper grade line would have been only about \$70.

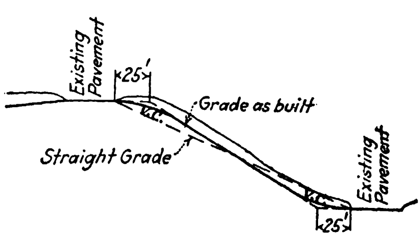


FIG. 15-14.—Use of short vertical curves.

This figure also illustrates the fault of the straight grade from A to B which would be both expensive and unsuited to the topography.

Figure 15-14 shows how the sharp breaks of grade at existing paved intersections made by a straight grade line from street to street, and also its failure to follow the topography, may be

corrected by using a slightly steeper grade and short vertical curves at each end. This device of steepening the grade and inserting vertical curves is one which can often be advantageously employed.

One of the most common faults, especially in flat territory, is to set the pavement too high. In the attempt to reduce the cost the pavement is "set on top of the ground." The grade should be so established as to give the proper cross-section to the street and the necessary earthwork done to accomplish this.

Maximum Grades.—Streets are as often paved for the sake of appearance, sanitation, and cleanliness as to facilitate traffic. Moreover, the pavement is usually placed after the land is developed and therefore the grades must be in accordance with the ground. This sometimes provides grades greatly in excess of those considered either desirable or safe for traffic. Occasionally, on main thoroughfares, grade reduction is possible and can be analyzed as outlined earlier in this chapter.

Grade Crossings.—At grade crossings, it is necessary to eliminate the crown and bring the entire surface of the pavement to the plane of the top of rail. The top of curb is brought to top of rail and the height of curb, or depth of gutter, gradually reduced to zero at the rail. This should be accomplished in not less than 25 ft. in order to avoid a bump to traffic running near the curb as well as for the sake of appearance. The pavement surface is gradually warped from normal crown to a straight line at the track. This should also be done in not less than 25 ft. and preferably in a longer distance because the center-line slope is changed by the difference in normal crown and normal curb height. Inlets should be placed as far from the track as the grades will permit and still provide a fall of about 3 in. in the gutter from the track to the inlet.

The general shape and layout of crossing approaches should be the same as outlined for rural highways, as shown in Figs. 15-6, 15-7, and 15-8.

Under- and Overcrossings.—The conditions governing the grades of underpasses and overhead crossings of railroads are, in general, the same as on country roads. If street cars use a subway, the clearance should be not less than 14 ft. Large interurban cars require 15 to 16 ft. The grades of the approaches should be as gentle as conditions will permit and the vertical curves as long as possible.

Streams.—Streams crossing city streets require careful consideration in establishing the grade line. Ample waterway may perhaps be obtainable only by raising the grade. And this in turn may cause complications farther along the street. The readjustments of street and property grades may be required with bridges of large size.

VERTICAL CURVES

Where two straight grades connect, the grade line is rounded off with a vertical curve, which is exactly analogous to the horizontal curve. Since the intersection angle is always small and gravity constantly holds the vehicle to the roadway, the effect of centrifugal force is imperceptible and the application of vertical curves is less complicated than horizontal curves. The parabola is universally used for vertical curves on account of the ease of computing its ordinates.

Minimum Curve.—If the total change of grade is less than about 0.1 percent, a vertical curve may be omitted. If the grade change is greater than about 0.1 percent, the omission of the curve will show a distinct break in grade. This may not be objectionable to traffic but has a bad appearance, especially if the pavement has curbs. Since a vertical curve is so easily installed there is no valid reason for omitting it.

Minimum Length.—Vertical curves on highways are designated by their length. The minimum length is normally governed by the distance between grade stakes. The *P.I.* of the curve should always be made to come at a regular stake for the sake of convenience in computing and staking the curves. The minimum length then becomes twice the distance between grade stakes. In the best practice, grade stakes are placed not more than 25 ft. apart on vertical curves and hence the normal minimum length of curve is 50 ft. Occasionally it may be necessary to use shorter curves and modify the staking to suit.

Sight Distance.—At summits of steep grades the length of the curve may depend on the necessary sight distance. On single-track roads this sight distance should always be something more than the sum of the distances in which the vehicles can easily stop. On double-track paved roads, the sight distance should be such that a driver can observe an approaching vehicle without being startled when traveling at normal road speeds and with the corresponding degree of concentration of attention given

the road. On account of increasing automobile speeds a minimum sight distance of 600 ft. is desirable. In Fig. 15-15

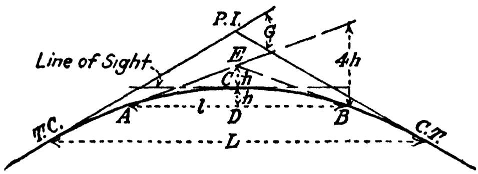


FIG. 15-15.—Sight distance on vertical curve.

G = total change of grade in percent.
L = minimum length of vertical curve in stations.
g = total change of grade between the vehicles A and B, both on the curve.
l = sight distance in stations.
h = vertical height in feet of the line of sight above the roadway, assumed the same for both vehicles and usually taken as 5 ft.

From the properties of the parabola

$$EC = CD = h$$

From the figure

$$g = \frac{4h}{\frac{1}{2}l} = \frac{8h}{l} \qquad (15\text{-}20)$$

From which

$$L = \frac{l^2G}{8h} \qquad (15\text{-}21)$$

Equation 15-20 may be used to compute the possible sight distance for a given change of grade, or the maximum change of grade for a given sight distance.

Equation 15-21 gives the total minimum length of curve for a given change of grade and a given sight distance. This value is exact when g is less than G. When g is greater than G the results are somewhat too large, since one or both vehicles would be on tangent but this is on the safe side.

Choosing Length of Curve.—The foregoing equations give the minimum length of curve. Something more than the minimum should always be used if possible, and the present tendency is toward longer curves. The grade line with long easy vertical curves that fit the topography is much more pleasing in appear-

ance, as well as safer and more convenient, than the one with short, choppy curves.

For ease in calculating and staking out, the length of the vertical curves should always be made some multiple of twice the distance between grade stakes. Thus if stakes are set 25 ft. apart, the length should be some multiple of 50 ft. Each tangent will then be some multiple of the normal stake spacing.

It is sometimes claimed that long vertical curves add to the earthwork. This is not necessarily true. If the tangents and curves are studied together in laying the grade line, long curves not only need not add to the earthwork but often will reduce it.

Low Point.—Since drainage facilities must be provided in all sags, it frequently happens that the position of the low point on a vertical curve must be located. Since the low point is where the slope of the curve is zero, it follows that

$$X = \frac{LG_1}{G_1 - G_2} \tag{15-22}$$

where X is the distance of the low point in feet from the end of the curve on the G_1 grade, L is the length of the vertical curve in feet, while G_1 and G_2 are the two grades in percent and must be used with their proper algebraic signs.

Example.—A vertical curve 600 ft. long joins a -6 percent grade with a $+4$ percent grade. The distance from the end of the curve on the -6 percent grade is

$$X = \frac{600 \times -6}{-6 - (+4)} = 360 \text{ ft.}$$

Equation 15-22 can also be used to find the location of the high point at a crest.

Computing Vertical Curves.—In Fig. 15-16, A and B are the $T.C.$ and $C.T.$, respectively, of a vertical curve of length L with the $P.I.$ at C. Since all distances are theoretically measured on the horizontal, the tangent distances are equal to $\frac{1}{2}L$, from which the station numbers of A and B are found from that of C.

D, E, F, G, etc., are points where grade stakes are required, at equal distances apart, there being n such distances on each side of C.

The elevations of the tangents at D, E, F, G, etc., are first computed and checked.

The elevation of N, the mid-point of AB, is easily found since it is the mean of the elevations of A and B.

From the properties of the parabola $CM = MN$; hence the elevation of M and the ordinate CM can be computed.

The ordinates from the tangents to a parabola vary with the square of the distance from the point of tangency.

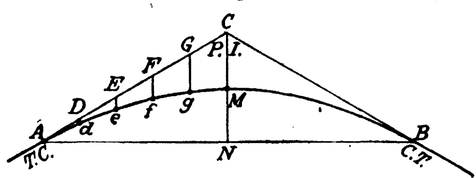


FIG. 15-16.—Elevations on vertical curve.

Therefore, $Dd:CM::\overline{AD}^2:\overline{AC}^2$
but AD is one unit of n equal units between A and C; hence

$$Dd:CM::1^2:n^2 \quad \text{or} \quad Dd = \frac{CM}{n^2}$$

Similarly

$$\begin{aligned} Ee &= Dd \times 2^2 \\ Ff &= Dd \times 3^2 \\ CM &= Dd \times n^2 \end{aligned}$$

The ordinate for each point between A and C having been computed, the elevations of the points on the curve are found by correcting the corresponding elevations on the tangent by these ordinates.

Since the curve is symmetrical the ordinates for the points between C and B are the same as for the corresponding points on the first half of the curve.

Compound Vertical Curves.—Sometimes it is found that a simple vertical curve does not properly fit the ground. In this case curves of some other form than the parabola are occasionally used. It is, however, both simpler and easier to use two or more simple parabolas compounded. The common tangents of suitable length are spotted on the profile and the individual curves worked out as above.

Problems

15-1. Assume $e_h = 0.15$, $e_l = 0.12$, $R_r = 50$, average car weight = 3,500 lb., and gasoline at 16 cts. per gallon. Compute the fuel cost of 200 ft. of rise and fall if both ascending and descending grades are 10 percent and a 3 percent grade can be coasted freely.

15-2. Compute the distance equivalent for the conditions in Prob. 15-1.

15-3. A car can develop an average tractive effort of 180 lb. per ton, the road resistance is 50 lb. per ton, a speed of 60 m.p.h. can be attained at the bottom of a grade 1,600 ft. long and 30 m.p.h. at the top. What is the percent grade?

15-4. What is the safe descending grade for the conditions in Prob 15-3?

15-5. What is the economic ascending grade of indefinite length for the car and road in Prob. 15-3?

15-6. In Fig. 15-1, $h = 200$ ft., $L = 1{,}200$ ft., and G_a is as determined in Prob. 15-5. If the annual traffic is 320,000 tons and the other factors as in Prob. 15-1, what would be the annual saving by reducing the grade to G_a?

15-7. What would be the permissible expenditure to reduce the grade as determined in Prob. 15-6 if the money is to be obtained by 20-year 4½ percent serial bonds?

15-8. A railroad on a level grade crosses a highway on a 1 percent grade at an elevation 6 ft. above the road, and at an angle of 30 deg. Design a crossing for a rural pavement 20 ft. wide with a maximum tilt of 0.5 ft.

15-9. Street A falls to the east on a 1.8 percent grade, street B to the south on a 1.0 percent. Both streets are 72 ft. wide with pavements 36 ft. back to back of curbs and 15-ft. corner radii. Both grades are to be carried through on the center lines. One-half the tilt is to be taken out at the property lines. Design the curb grades for 100 ft. each way from the center of intersection where both pavements are to be level transversely.

15-10. Same as Prob. 15-9 except that the streets intersect at 60 deg. and the grades are to be figured back 50 ft. from the acute corners.

15-11. Street A falls to the east on a 2.4 percent grade, street B to south on a 3.8 percent. Both streets are 80 ft. wide with 56-ft. pavements, back to back of curbs, in a retail business district. The property corner elevations are: NW 716.0, SW 711.0, SE 709.8, and NE 713.5. Design the curb grades for the intersection with corner radii of 15 ft.

15-12. A +6.5 percent grade meets a −5.2 percent grade. Compute the theoretical length for a sight distance of 600 ft. and choose the proper length to use.

15-13. Compute the elevations for points 25 ft. apart on the curve adopted in Prob. 15-12, assuming the $P.I.$ to be at station 13 + 00 with an elevation of 291.50.

15-14. A −2.0 percent grade meets a +1.6 at station 16 + 50. Find the station number of the low point on a vertical curve 400 ft. long.

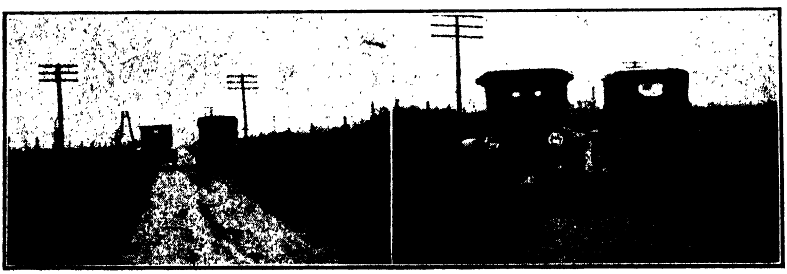
CHAPTER 16

WIDTH AND CAPACITY

RURAL ROADS

A highway must have sufficient capacity to accommodate the traffic which desires to use it. The weight capacity of a roadway is determined by its structural design. The volume capacity is primarily governed by the width. Horizontal and vertical alinement have secondary effects while intersections, railroad crossings, bridges, etc., still further affect capacity.

On rural roads the items of width that must be considered are (1) the width of pavement or traveled way, (2) the graded width or distance between shoulder lines, and (3) the total width of right-of-way.



Normal Bad weather

FIG. 16-1.—Passing on single-track road.

Single-track Road.—The single-track road is one having an improved surface of only sufficient width to accommodate a single vehicle. For vehicles to pass it is necessary for one vehicle to get off of the improved way, or for both to run half on and half off. Such roads, therefore must have a sufficient width of graded way to permit such passing. In addition the shoulders must be such as will permit passing with reasonable facility under all weather conditions.

The width of tread of the American automobile is 56 to 62 in. and the over-all width is about 70 to 72 in. Large trucks have

treads up to 7 ft., but the widths are almost universally limited to 8 ft. The minimum width of improved surface therefore should be 9 ft. This may be modified by the type of surface, while considerations of future widening may also change this width. If there is any probability of widening, the single-track surface should be designed so as to be readily incorporated into the roadway of greater width. This normally means that with high-type surfaces the width should be one-half the width of a double-track road.

The single-track road is decidedly unpopular. The traveling public greatly dislikes running partially off the pavement, even

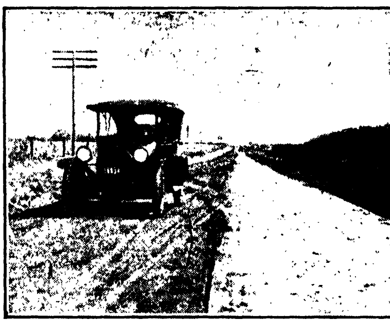


FIG. 16-2.—Single-track pavement on full-width graded way.

FIG. 16-3.—Passing on a double-track roadway.

occasionally, especially if the shoulder is slippery or muddy. The statement is frequently made that no improved surface should be narrower than will permit two vehicles to pass. This is true from the standpoint of convenience but it is not economically sound. Under certain conditions of funds and traffic, the single-track road is entirely justifiable. The first requirement of a road system is *length*. Thus, if funds will permit a single-track pavement to be built between two points but would provide a double-track roadway only part way, the former will invariably prove the better, the more convenient, and the more economical. Again, the volume of traffic may not justify the added cost of the greater width but will make profitable the building of a single-track surface. If the traffic volume is large the single track is inadequate; but even in this case it is generally preferable and more economical to have a narrow road all the way instead of a wide road part way and none at all for the remainder of the distance.

Traffic Limit of Single Track.—Observation indicates that two vehicles approaching each other on a single-track road begin to turn out when 150 to 250 ft. apart and turn in again in somewhat less distance, making the total distance required to pass 300 to 400 ft. Observation also indicates that, if the distance between turnouts is less than about twice the passing distance, the vehicles will not turn in again. Thus, if turnouts occur closer together than ¼ mile, the traffic tends to run double track.

The maximum frequency of turnout permissible on a single-track road is thus four per mile. This should occur only at the times of extreme density which, in order to avoid congestion, should be limited to about twice the normal maximum. A. N. Johnson[1] states that for certain roads the seasonal average was about 0.6 the seasonal maximum, and that the daily average was also about 0.6 of the daily maximum. On this basis the average frequency of turnout should not exceed about one-third the maximum frequency and therefore may be taken as *one per mile*. At an average speed of 30 m.p.h. this would accommodate a maximum hourly traffic in both directions of 60 vehicles. Traffic surveys in Illinois[2] indicate that the total daily traffic may be taken as ten times the maximum hourly traffic. A single-track road may therefore be expected to give satisfactory and economic service up to an average of about 600 vehicles per day, provided the shoulders can be reasonably well maintained at all times under one-half this traffic.

Double-track Roads.—When the limits of the single-track road have been reached, or if the public is willing to spend the money for the greater convenience and satisfaction of the wider width, the road should be double tracked. By taking into consideration the size and speed of vehicles and the clearance taken by most drivers the minimum width of a double-track modern roadway should be not less than 18 ft. If many large trucks or busses are present the width should be at least 22 ft. because the average driver tends to keep farther away from a vehicle larger and higher than his own, and more clearance is needed.

The double-track road permits traffic in opposite directions to pass at any point. Vehicles overtaking others traveling in the

[1] *Proc.* Am. Soc. C.E., Vol. LI, No. 5, pp. 748–756, May, 1925.

[2] *Report of the Survey of Traffic on Illinois State Highways*, Ill. Div. of Highways, Springfield, December, 1932.

same direction must find opportunity to pass as traffic in the opposite direction permits. Since the width is only sufficient for two vehicles, the majority of the traffic is compelled to run in definite lanes. This concentrates the wear and loads due to vehicles into narrow spaces and exerts a marked effect on the design of the surface and base.

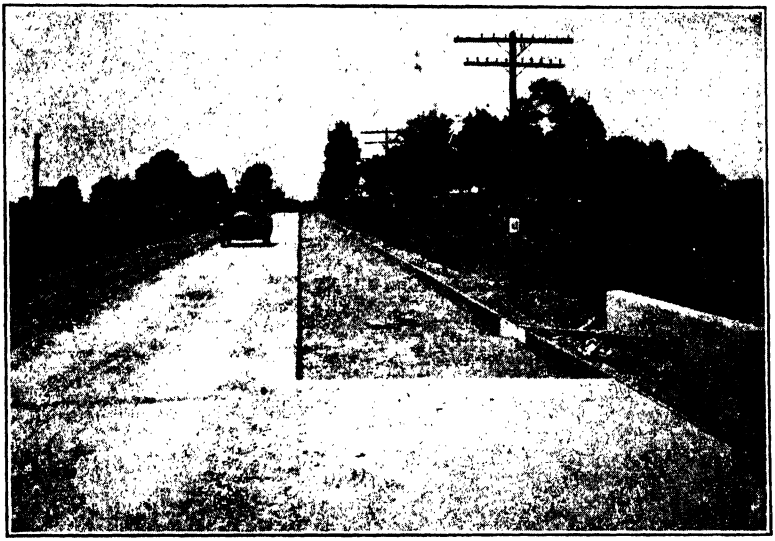


FIG. 16-4.—Double tracking an existing pavement.

Capacity of Double Track.—The capacity of any road depends on the average speed and spacing of the vehicles, or

$$N = \frac{5{,}280S}{l + d} \tag{16-1}$$

where N is the number of vehicles per hour in a single line of traffic, S is the speed in miles per hour, l is the average length of vehicles in feet, and d is the clearance, or distance between vehicles in feet.

If it were possible to compel the vehicles to travel at a uniform speed and at the minimum spacing, the maximum capacity could be obtained. Actually, vehicles move at different speeds and there are many factors which cause variations in the spacing. It is therefore necessary to determine probable normal values of S, l, and d before the actual capacity can be estimated.

If all vehicles applied their brakes at the same instant and with the same force, the clearance d would theoretically be *zero* or, with a given spacing, the vehicles would stop without changing this spacing. Practically, this condition is impossible. An interval of time always elapses between the instant of application of brakes by a leading car and the instant when a following driver recognizes the fact and applies his brakes. The length of this interval depends primarily on the degree of concentration of the driver's attention on the traffic. On crowded city boulevards this interval may often be as low as 0.5 sec. On the open road the driver tends to relax and divide his attention and the

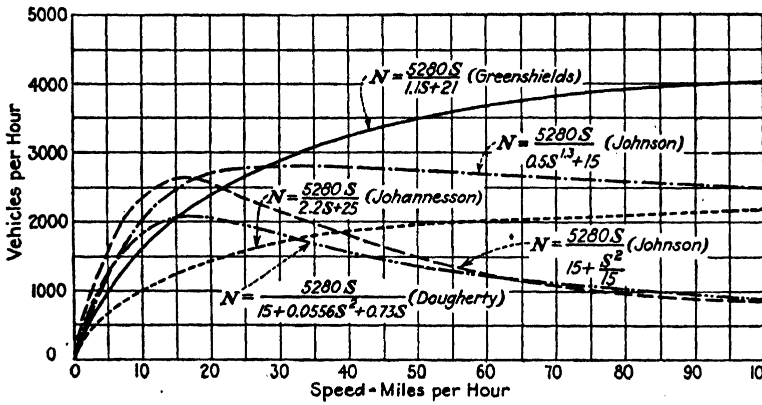


FIG. 16-5.—Various formulas for estimating the capacity of a traffic lane, based on various observations and assumptions.

time interval may increase to 10 sec. or more. As traffic becomes denser he concentrates more of his attention and the spacing decreases at the same speed.

Several formulas of the general form of Eq. (16-1) have been proposed for computing the capacity of traffic lanes. The more important of these, together with capacity curves computed by them, are shown in Fig. 16-5.[1] Each of these formulas is based on certain assumptions or conditions. For example, the Greenshields formula gives the extreme maximum flow based on a continuous line of traffic moving without interference and at the minimum spacing found in field observations. On the other hand, Johnson's formula is based on an average spacing of traffic as observed on the road. It therefore makes some allow-

[1] The Photographic Method of Studying Traffic Behavior, *Proc.*, Thirteenth Ann. Meeting, Highway Research Board, p. 382, 1933.

ance for the interference to movement by grouping and by traffic passing in the opposite direction. None of these formulas can be said to give the actual capacity of a two-lane road under actual operating conditions.

A. N. Johnson concludes from his observations that congestion begins to appear for short intervals when the total flow (both directions) reaches about 1,000 vehicles per hour at a speed of about 35 m.p.h. Since a satisfactory road should be free from congestion except under extreme conditions, this value should be considered the normal maximum hourly traffic. Traffic surveys have shown that the total daily traffic is about ten times the maximum hourly traffic and therefore it may be taken that the congestion-free traffic capacity of a two-lane road is about 10,000 vehicles per day.[1]

The Three-lane Road.—Attempts have been made to increase capacity by building three-lane roads 24 to 30 ft. in width. Although some increase in capacity is obtained, the results have not been satisfactory or economical, except in a few special cases where the traffic for certain periods is much denser in one direction than the other. The two principal difficulties seem to be, first, to get normal traffic to run in its proper lanes leaving the third one free for passing traffic and, second, to control the use of the third lane. The road with three lanes for running traffic is, therefore, normally not satisfactory. On the other hand many three-lane streets seem to operate well.

Multiple-lane Roads.—Where greater capacity is required, multiple-lane roads are necessary. These should be made in multiples of two for running traffic. The capacity of the multiple-lane road may be estimated on the basis of 10,000 vehicles per day for each two lanes. With more than six lanes, however, trouble is experienced at intersections in crossing or in getting on to and off the roads. Therefore the six-lane road should be considered about the maximum to use. If greater capacity is required, two parallel four-lane roadways will generally be more convenient and will have greater capacity than one eight-lane road.

Graded Width.—The graded width depends on the width of traveled way, whether it is curbed or not, and on the use of the shoulders.

[1] *Report of the Survey of Traffic on Illinois State Highways*, Ill. Div. of Highways, Springfield, December, 1932.

A single-track road must always have at least one shoulder wide enough to permit passing; hence the minimum graded width is about 20 ft. On a double-track road the shoulder may under some conditions be only a berm 2 to 3 ft. to support the surfacing material, making the minimum graded width 22 to 26 ft. If guard fences are required, about 2 ft. more is necessary on each side, making a total width of 26 to 30. On busy roads, however, space for possible parking should be provided, preferably on both shoulders, which, therefore, should be 10 to 12 ft. wide. This makes the width required 40 ft. Since it is desirable to maintain a uniform width and since guard fences are not continuous, additional space is not provided for guard fences on these roads. Wider roadways require the same shoulder widths; therefore the graded width is increased by the increase in width of pavement. A six-lane road 60 ft. wide would require a graded width of about 80 ft.

If the roadway has a normal curb so that traffic does not leave the pavement, the shoulders need only to be berms wide enough to support the pavement or to carry a guard fence. This requires only 3 to 6 ft. Such a pavement should be not less than 28 ft. back to back of curbs to allow two lanes of running and one of parking traffic; hence the minimum graded width is 34 to 40 ft.

Width of Right-of-way.—The width of right-of-way is governed by the graded width, the space required for ditches, and the slopes of cuts and fills. A minimum of about 3 ft. is required between shoulder line and center line of ditch and 2 ft. for back slopes. A single-track road can therefore be put on a 30-ft. right-of-way. A double-track roadway with ample shoulders will require a right-of-way 50 to 60 ft. wide. This makes no allowance for cuts and fills over 2 or 3 ft. in depth.

On a fill the side slope begins at the shoulder line and may extend to the property line. The width of right-of-way will then depend on the rate of side slope, the height of fill, and the graded width. If the last is 30 ft., the side slopes are $1\frac{1}{2}:1$, and the fill 10 ft. high, the right-of-way required is 60 ft. In cuts with the side slopes already mentioned, a width of 66 ft. is required to accommodate the side ditches. If a wider roadway is necessary, or if a sidewalk, foot path, or berm is required, the minimum width is increased correspondingly.

The following widths of right-of-way are recommended:

Lanes and private drives	20 to 30 ft.
Sparsely traveled local roads	40 to 60 ft.
Ordinary secondary roads	60 to 72 ft.
Primary roads	80 to 100 ft.
Crowded trunk roads (multiple lane)	80 to 200 ft.

Increasing the Capacity.—It is becoming more frequently necessary to increase the capacity of existing roads as they approach the large cities. To do so requires greater width of roadway and this in return may demand greater right-of-way. No road, however, need have greater capacity than the street to which it connects. This points out the necessity of choosing proper entries to the cities. It also indicates the mistake of making a roadway of appreciably greater width than the pavement on the connecting street.

In most cases the widening has been accomplished by making a multiple-lane road of the conventional type, *i.e.*, an uncurbed pavement with shoulders and side ditches. In many cases this has necessitated a wider right-of-way. Such increased width of right-of-way is desirable, even if greater than the connecting street, because it gives a safer and better-looking road and can be developed into a better street. Frequently the additional right-of-way can be secured only at prohibitive cost. The traffic capacity can then be increased only by changing the road to city-street type with a curbed pavement occupying the space ordinarily taken up by the shoulders and side ditches. An underground, or storm sewer, system of drainage must be included. Such a system will cost roughly $6,000 to $10,000 per mile but its efficiency is high and its maintenance costs much less than the open side ditch. Numerous attempts have been made to secure wider right-of-way when the pavement could have been widened by filling the ditches and building curbs and storm drains at less cost than the new right-of-way.

CITY STREETS[1]

In the early days a city street, even in the business district, provided nothing more than space for vehicular and pedestrian traffic. The modern street, in addition to a greatly augmented

[1] See Use and Capacity of City Streets, *Trans.*, A.S.C.E., No. 99, p. 1012, 1934.

traffic, must also provide right-of-way for many utilities and conveniences demanded by present-day living. Street railways, telephone and telegraph lines, storm and sanitary sewers, water and gas mains, electric power circuits, lighting systems, etc., must all be accommodated in our streets. The problem of street design, therefore, is a complicated one and the demand for right-of-way is ever increasing.

Width for Running Traffic.—It is now generally agreed that a traffic lane should be about 11 ft. wide. High-speed traffic or traffic containing many large trucks or busses may use this space. As traffic becomes more dense there is a tendency to crowd

FIG. 16-6.—Three lines of automobiles on a 28-ft. pavement. Compare with FIG. 16-7.

laterally as well as to close up longitudinally. Less space is then occupied by each lane and additional lanes develop. Thus a 66-ft. pavement designed to carry six lanes may be found to be actually carrying seven or eight lanes in periods of congestion. In the smaller city, 10 ft. per traffic lane is generally sufficient.

Width for Parked Traffic.—If the vehicles park parallel to the curb, a width of 7 ft. is sufficient for automobiles but 8 ft. is desirable for ease in parking. Large trucks may require 10 ft. If diagonal and 90-deg. parking are practiced, about 16 ft. is required for automobiles and 20 ft. or more for large trucks. Since large trucks, in controlling numbers, are generally found parked on business streets only, and since diagonal parking also is usually limited to business districts, the wider widths should apply to business streets, while the narrower widths may be used on residence streets.

Width for Street Cars.—Few automobile drivers will drive as close to streetcars as they will to other vehicles. Furthermore,

the streetcar follows a fixed path and all of the duty of avoiding collision is transferred to the motor car. Greater clearance is therefore desirable where these large vehicles are common.

While many street cars are only 8 ft. wide, there do exist wider cars and interurban cars may be 10 ft. wide. When all factors are taken into consideration, a minimum width of 10 ft. should be assigned to the single-track street railway. Where more than one track exists, the distance between the center lines of extreme tracks must be added to the 10 ft.

Where streetcar traffic is infrequent and vehicular traffic moderate, so that the latter is little interfered with, the street

FIG. 16-7.—Four lines of traffic on a 28-ft. pavement. This occurs frequently. Compare with Figs. 16-6 and 16-8.

railway may be neglected in considering the width of pavement. But as either vehicular or streetcar traffic increases, the interference is greater and the full width should be provided.

Width of Pavement.—Residence streets serving only a few houses may be paved only of double-track width. This will permit two vehicles to pass or accommodate an occasional parked car since traffic is sparse and will adjust itself to the conditions.

Residential streets with detached dwellings can be well served with a three-lane pavement. This should be not less than 27 ft. between curbs. A streetcar track with infrequent service need not add to the width. If streetcar service is frequent or vehicular traffic considerable, the width should be increased to provide sufficient room on each side of the track for a moving vehicle to pass between a streetcar and a vehicle standing at the curb. By allowing 7 ft. for parked traffic, 10 ft. for a running lane, and 10 ft. for the street car the minimum width is 44 ft. Even at this width many drivers hesitate to pass between the streetcar and the

parked car; hence additional width is desirable. If the widths previously recommended are used, the minimum width is 46 ft. A double-track streetcar line would require 50 to 60 ft. of pavement width.

During the fall of 1934 the author made a series of observations on a street carrying about 10,000 vehicles per day. The pavement was 36 ft. wide, comprising two 10-ft. running lanes and two 8-ft. parking lanes. Where parking was intermittent, traffic spread apart to permit passing, approximately 50 percent of the vehicles encroaching 2 to 3 ft. on the parking lanes. Where

FIG. 16-8.—Four lines of traffic on a 36-ft. pavement. Note the generous space. Sometimes a fifth line appears.

parking was continuous, traffic slowed down and crowded together to the point of congestion. On another street carrying about 12,000 vehicles per day with a pavement 42 ft. wide the operation was largely on a three-lane basis and practically no congestion occurred even with continuous parking. From these observations the conclusion was reached that such streets should have pavements 42 to 46 ft. wide instead of the conventional 20-ft. strip for running traffic flanked by parking strips.

Pavement on business streets should be somewhat wider than on residential streets for the sake of convenience and safety but should not be wide enough to create the temptation to insert another traffic lane. With diagonal parking, correspondingly greater width is necessary.

Sidewalks and Parkings.—Trees should be considered an essential feature of a residence street and, if they are to flourish, they must have reasonable space. Trees may be planted within about 4 ft. of the sidewalk. Trenches for utilities should not be

closer than 4 ft. to a tree. If two service mains are permitted on each side of the street, a minimum of 4 ft. is required for trenches and at least 2 ft. should be allowed between trench and curb. This makes the minimum desirable width of parking 14 ft. This may, however, be reduced 1 or 2 ft. without serious objection. Sometimes a narrower parking can be utilized by laying utilities sufficiently deep to tunnel under the trees. It is rarely possible to have trees on business streets. The demand for sidewalk and pavement space generally requires all of the available right-of-way. The small space of open ground and poor facilities for light and air make growing conditions unsatisfactory and trees rarely flourish. It is better to provide numerous small parks and open spaces for planting than to attempt it along business streets.

On business streets greater width of sidewalk is necessary and with increased pavement width the entire width of street is covered with walk or pavement. This places all underground utilities under some form of pavement; consequently they should be designed to require the minimum of attention. Many pavement openings could be eliminated with more care and foresight in the design and construction of the underground conduits.

Total Width.—It is rarely possible to secure a width of right-of-way to agree with present requirements. It is generally necessary to adapt the improvements to a right-of-way fixed a number of years previously. Occasionally streets are widened even to the extent of removing or cutting off buildings. Such work is expensive and only the large cities can finance such projects. On the other hand, some foresight can be applied to new plats to avoid similar trouble in the future. By allowing 6 ft. for each sidewalk, 14 ft. for each parking, and 28 ft. for the pavement, the width of right-of-way for a normal residence street is 68 ft. This may be condensed to the conventional 4-rod or 66-ft. right-of-way but preferably should be increased to 70 or 72 ft. With light, air, and the possible development taken into consideration, no city street should ever be less than 60 ft. wide.

Streets which are to carry trunk highways through residence districts should be at least 80 ft. wide in the smaller cities and 100 ft. in larger cities. Business streets should be 80 to 100 ft. in the smaller cities and 100 to 200 ft. in the larger cities. Boulevards may be 100 to 200 ft. wide depending on the traffic demands and

the desire for parkway beautification. When the total street width becomes more than about 200 ft., the intersections offer objectionable delay to vehicular and pedestrian traffic and tend to increase congestion; hence this may be considered the approximate limit of desirable width.

MISCELLANEOUS

Intersections.—Intersections reduce the capacities of the roads involved. Crossing traffic interferes with the free movement on either road. On roads of the same dimensions the maximum capacity of the intersection for crossing traffic is theoretically equal to that of either road, or if the traffic is equal the maximum theoretical capacity of each is only 50 percent. Cross movements cannot be made at the same rate as direct movement; therefore the capacity of each road is less than 50 percent, probably never more than 45 percent, or the total capacity of the intersection is not over 90 percent of that of either one of the two roads. If the intersection is small, turning traffic will still further reduce the capacity. If provision for turning or transfer traffic is made outside the intersection proper by means of Y-connections, the road capacity may be increased somewhat depending on the amount of turning traffic.

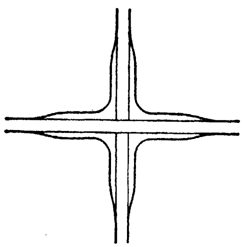


FIG. 16-9.—Widened intersection.

The *widened intersection* shown in Fig. 16-9 was devised in the attempt to increase the capacity by providing more lanes of traffic. When controlled by a signal, traffic may spread out into the extra lanes and thus some increase of capacity may be obtained. When no signal is present the tendency is to remain in the straight lane; hence little is gained. In either case the added width adds to the time for vehicles to cross and thus tends to counteract any advantage gained by increasing the number of lanes. Turning traffic may be somewhat facilitated by widening. On the whole the efficiency of an intersection of this kind is questionable.

The capacity of street intersections, especially where several streets cross in a group, has been increased by means of the gyratory system[1] or *traffic circle* as shown in Fig. 16-10. In this

[1] Traffic Circles and Rotary Traffic, *Civil Eng.*, Vol. 3, No. 11, p. 626, November, 1933.

scheme the intersection is made in the form of a circle. Each vehicle on entering the circle turns to the right and then proceeds in a counterclockwise direction around the circle to the street

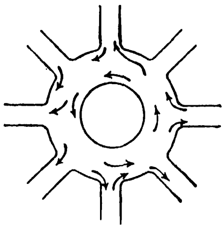


FIG. 16-10.—Gyratory intersection.

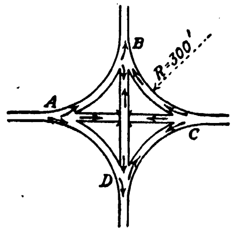


FIG. 16-11.—Y-connections at intersection.

desired and leaves by again turning to the right. The capacity of such an intersection is governed by the radius of the circle and the width of the circular way. The inner radius should be not less than about 100 ft. and the width of roadway about one-third the sum of the widths of the entering streets.

The relation of traffic-control methods to the capacity of intersections is treated in Chap. 20.

Grade Separations.—The most effective means of increasing the capacity of intersections is grade separation. In this way,

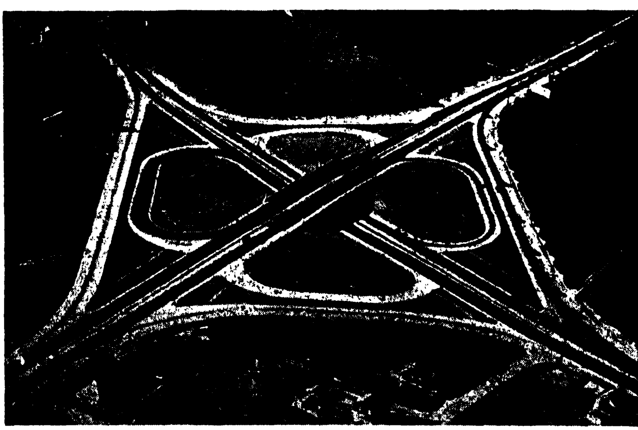


FIG. 16-12.—Cloverleaf intersection.

the crossing traffic is entirely separated and offers no mutual interference. If only crossing traffic were involved the grade separation would entirely solve the problem but unfortunately,

for this ideal condition, traffic turning from one road to the other must be accommodated.

Since there is a difference of elevation of the two roads of 15 to 20 ft., it is necessary that the connecting curves be of some length to make reasonable grades on the connections. Figures 16-11 and 16-12 show two methods of providing for this transfer of traffic.

In Fig. 16-11 the connections are made in the form of the familiar Y-track used on railroads. Each branch carries traffic in both directions and forms a direct connection between the two roads. Eastbound traffic at *A* desiring to go south can swing into the curve with little or no interference to other traffic. At *D* it must enter the traffic flow at a small angle but this is often an advantage rather than a handicap as there is greater room for the adjustment of the spacing of the vehicles.

Traffic at *A* desiring to go north must swing to the left, crossing the west-bound traffic lane at a small angle. The widening of the pavement due to the curve offers some opportunity for doing this without undue interference. At *B* it must cross the south-bound lane and enter the north bound at a flat angle under similar conditions.

Figure 16-12[1] shows a type of intersection known as a *cloverleaf* junction. The direct traffic is accommodated by the grade separation. Right turns are made in the outer Y-branches in the same way as in Fig. 16-11. Left turns are made by first passing through the grade separation and then turning *right* on the inner loop or cloverleaf. In this way there is no crossing of adverse traffic lanes; hence the maximum safety and freedom from interference. The only objections to the scheme are that it requires considerable space, which may be hard to get, and the cost is high. On the other hand, the plan is justifiable when there is a large volume of both through and transferring traffic.

Bridges.—Bridges are rarely wide enough. The desire to reduce cost keeps the bridges down to the very minimum of width. In addition, the bridge designer frequently makes the mistake of increasing his live loads for small increases in width. The live load to be carried on a 24-ft. road is identical with that on a 20 ft. so the only increase in load is the dead load incident to the greater width of floor.

[1] Separating Grades at Highway Intersections, *Civil Eng.*, Vol. 3, No. 2, p. 79, February, 1933.

Culverts should extend the full width of graded way on rural roads and the entire width of right-of-way on city streets. Bridges of longer span may be reduced in width but no bridge should be narrower than the pavement on each side of it and preferably at least 4 ft. wider. At best a bridge or culvert is a point of potential danger and tends to interfere with traffic movement. If it is narrow, congestion develops and the danger is increased.

High railings, girders, or trusses along the edge of the roadway cause the majority of drivers to crowd toward the middle of the road away from the structure. This is largely due to, or at least is aggravated by, the driver's position on the left side of the vehicle. Extra clearance is therefore needed to prevail on traffic to run straight at ordinary road speeds. About 3 ft. is necessary for this purpose; therefore the minimum width of a bridge for an 20-ft. pavement is 26 ft., and for a 24-ft. pavement 30 ft. A curb and hub guard should always be provided to prevent the vehicles from running off the paved way and striking the structure.

FIG. 16-13.—Evidence of the need for greater width of bridges. Traffic crowds to the center on account of the high girders. The oil streaks on the pavement are about 2 ft. closer together on the bridge than elsewhere.

If there is any appreciable number of pedestrians crossing the bridge, at least one sidewalk should be provided. If it is placed next to the roadway, the two should be separated by a curb not less than 7 in. high. In rural districts, these walks may be as narrow as 4 ft. but on city streets the minimum should be 6 ft. Normally two sidewalks should be provided on city streets. These may be carried outside the trusses or girders, which has the advantage of separating them from the roadway.

Problems

16-1. The estimated traffic on a certain road is 14,000 per day. How many lanes would be required and what should be the total width of pavement?

16-2. Draw a cross-section of the road from Prob. 16-1 using 10-ft. shoulders and $1\frac{1}{2}:1$ side slopes on fill. What would be the minimum width of right-of-way for a fill 30 ft. high?

16-3. The same road when in cut is to have curb-and-gutter 2 ft. wide on each side and a level berm back of the curb for 6 ft. Draw a cross-section with 1:1 side slopes and determine the width of right-of-way for a cut 25 ft. deep.

16-4. What should be the width including curb-and-gutter of the pavement on a street carrying double-track street railway, tracks 9.5 ft. on centers, with frequent service, where parallel parking is needed and two running lanes in each direction?

16-5. Two 40-ft. pavements in 100-ft. rights-of-way cross at 90 deg. Lay out a cloverleaf using a minimum radius at edge of pavement of 30 ft. on the leaves and 100 ft. on the Y's. Connections to be 20 ft. wide and the leaves and Y's must be separated at least 3 ft. Determine the additional right-of-way required, the right-of-way lines to be 30 ft. from edge of pavement at all points.

CHAPTER 17

SURVEYS, PLANS, ESTIMATES

SURVEYS

Surveys of various kinds are fundamental to all engineering projects. Those incident to highway work are known as *reconnaissance* surveys, *preliminary* surveys, *location* surveys, and *construction* surveys. The functions of these various surveys are essentially the same as for railroads. The details, therefore, are to be found in the standard books on railroad, highway, or route surveying. The term survey is also applied to the collecting of specific data of various kinds as in *traffic* surveys and *condition* surveys, etc.

Reconnaissance.—A reconnaissance is a rapid survey for the purpose of selecting one or more feasible routes for a proposed road. In case of an entirely new road or a relocation, the reconnaissance is essentially the same as in railroad work. Approximate methods of determining elevation and distance are used. The favorable routes are landmarked sufficiently to enable a preliminary survey to follow them. If a good topographic map of the territory is available the reconnaissance may be done entirely from the map.

In the case of existing roads, the reconnaissance is often for the purpose of determining which of several alternate roads is most susceptible of improvement. The work is best done by traveling the road in an automobile and sketching the salient features of the topography. Angles can be estimated, elevations determined by barometer, approximate grades determined by means of a clinometer and the distances taken from the odometer of the car.

Reconnaissance, as such, is almost unknown in city work. The street or streets to be improved should, however, be examined on the ground before making a preliminary survey to determine any special features, suitable dimensions, and the limits of the improvement.

Preliminary for New Road.—The purpose of a preliminary survey is to secure detailed data from which a suitable location can be projected and the various features of the road properly designed. The preliminary for a new road or a relocation is identical with the preliminary for a railway line.

By means of cross-sections, transit and stadia readings, plane table, airplane surveys, or any other convenient methods, notes are taken from which a complete topographic map can be made of a strip of land in which the road will be located. Complete data concerning all streams should be secured. They should be explored both up- and downstream for evidences of their character, elevation of high water, possibility of channel changes, etc. Information concerning the soil to be excavated, availability of local materials for construction, and all other pertinent information, including the names and addresses of land owners, should be secured. From these data, a paper location is worked out and the various features designed.

Preliminary for Road Improvement.—The preliminary for the improvement of an existing road is nearly the same as the foregoing. The differences are caused by the fact that the location is already fixed. A transit line is run and to this is tied in every feature of the old right-of-way. Cross-sections are taken, usually to the property lines unless the road is too narrow or the improvement is to have minor changes in location. The cross-sections should then be carried beyond the probable extension of the right-of-way. Data in regard to streams, materials, property, etc., should be included as before.

Preliminary for City Pavement.—A city is usually laid out and established some time before the paving project is proposed. If the sidewalks are built, or the property lines are definitely indicated, it is not necessary to run a transit line. In case of curved streets the center line should be approximately established in order that stationing may be reasonably correct. In case of straight streets with existing sidewalks, it is usually more convenient to do the measuring along the edge of the street, marking the stations on the walk. If the street system is rectangular, chaining on one side only is sufficient. If the intersections are oblique, chaining both sides is advisable. All intersecting streets and alleys should be located and any other features that may affect the design or the amount of the work.

Cross-sections are taken at intervals of 50 or 100 ft. The latter is sufficient in most cases but the former may be desirable if the changes of grade are numerous. Readings should also be taken on the center line of intersecting streets for approximately a block in each direction so as properly to design the intersection. If the adjacent parallel streets are paved, these cross profiles should include reading on these pavements. The existing drainage facilities should be examined and records made. If an outlet tile must be run to connect with the storm sewer on another street or to a natural outlet, a profile should be run of the proposed line. Data concerning streams should be collected the same as on rural roads.

Preliminary for Widening.—When a single-track road is to be double tracked, little may be needed in the way of a preliminary survey since the graded width is generally sufficient for the small additional width. If the original plans are available they can usually be used. If a two-lane road is to be made four lane or wider, a careful preliminary survey should be made, especially if the right-of-way must be widened. The data secured should cover every feature that is likely to be affected by the change.

When a city pavement is to be widened a preliminary survey should be made with great care and in great detail. Drainage facilities, parkways and sidewalks, private drives, public utilities, fire hydrants, lighting systems, shapes and dimensions of intersections, and a host of other things may be affected and definite information is necessary adequately to provide for them. Many of the defects in widened streets can be attributed to inadequate preliminary surveys.

Road Location Surveys.—After the plans have been completed and the contract let, the work must be located on the ground. The process is essentially the same as in railroad work. The paper location is followed except where obvious changes are necessary. Each transit point should be carefully referenced and witnessed so that it can be quickly and accurately replaced because the processes of construction invariably destroy the original stakes. Sometimes an offset line instead of the center line is run in order to avoid interference with the survey by the construction work.

Structures such as bridges, culverts, and farm entrances are staked out to suit the convenience of the contractor. The stakes must give him the exact location, dimensions, and elevation.

Street Pavement Location.—The first step in street pavement location is to establish the center line or its equivalent. This may be done from property-line stakes or known subdivision monuments. It is usually desirable to place the center line of pavement on the center line of street. If, however, the appearance, the convenience to traffic, or safety can be improved by shifting the center line of pavement to eliminate small jogs or angles, it should always be done, whether shown on the plans or not. The center line of intersecting streets must then be established.

With the center line as a base, curb stakes are driven to give line and grade. Two general systems are employed. In the first, a line of stakes is placed 2 to 3 ft. back of curb with their tops at the grade of top of curb or sometimes a fixed distance above or below it. This usually requires holes to be dug, which is slow and expensive. After the stakes are driven to grade, they are tacked for line. The entire process of rough grading and curb building is done from these stakes.

In the other method a line of stakes is driven 2 to 5 ft. back of curb, or far enough to be out of the way of the excavators. These stakes are driven flush with the ground and witnessed. Levels are taken on them and the contractor is given cuts from them by which he completes the rough grading. The engineer then sets the curb stakes in the excavation, 2 to 3 ft. *inside* the back of curb or 1 to 2 ft. from the edge of gutter slab. These stakes are driven to the grade of top of curb, edge of gutter, or a fixed distance above or below either, as is most convenient, and are tacked for line. This process requires two sets of stakes but is faster and cheaper, and generally more accurate than the former. The rough grading stakes do not require tacking and can be rapidly driven. The grade stakes are then set in open ground in the excavated area where they are easily seen, convenient to get at, and are driven to practically uniform depth. Occasionally local conditions limit the method which can be used.

At intersections stakes should be placed at the tangent points of the curb corners, at the ends of the turnout wings, the centers of the curb radii, and the middle of the curb arc. It is often convenient to use light chalk lines in staking an intersection. Work with them is faster and more convenient than with the transit and is sufficiently accurate.

Construction Surveys.—During the progress of construction surveys must be made to replace lost stakes and to supply new

stakes as the progress of the work demands. Location and construction surveys merge together and often no distinction is made.

In addition to surveys necessary to control the process of construction, measurements must be made at suitable intervals to determine the progress of the work in order to make partial payments to the contractor. After the work is finished a final measurement must be made of all the work done so as to make the final payment.

Monuments.—Another matter that demands care during construction is the preservation of monuments lying within the limits of the work. Every government survey monument, addition corner, and boundary marker must be accurately preserved. They should first be accurately referenced. The original monuments should be carefully lowered sufficiently to be cleared by the construction work and firmly reset to exact position. If they lie within the limits of the pavement some form of marker should be accurately placed in the pavement surface. Cast-iron or bronze monuments of special design are frequently used. They should be of such dimensions as to be easily found but not large enough to be objectionable to traffic or to maintenance work. They should be so designed that they can be permanently anchored in the pavement and not be displaced. Another method is to set a cast-iron valve box over the monument. Access can then be had directly to the original monument by opening the valve box.

Traffic Surveys.—Traffic surveys include the collection of data of various kinds relative to the character and movement of traffic. When well made and properly interpreted traffic surveys can be of great assistance in framing future road and street programs, in the selection of routes for improvement, in providing belts and bypasses, in securing parking facilities, in selecting systems of traffic regulation, and in many other problems related to the development and use of the highways.

A *volume survey* determines the number of vehicles which pass a given point in a given time. The rate of flow or *traffic density* is usually given in *vehicles per hour*, while the volume is frequently indicated by the number of vehicles per day. In general, the daily traffic is approximately ten times the maximum hourly traffic. *Minute-by-minute* variations are useful in studying proposed traffic-signal installations.

A *movement survey* is a volume survey at an intersection so taken as to show the volume on the various routes traversed through the intersection. Such surveys are very useful in traffic regulation and accident studies.

Origin and destination surveys collect data concerning these features of traffic and may also include information relative to

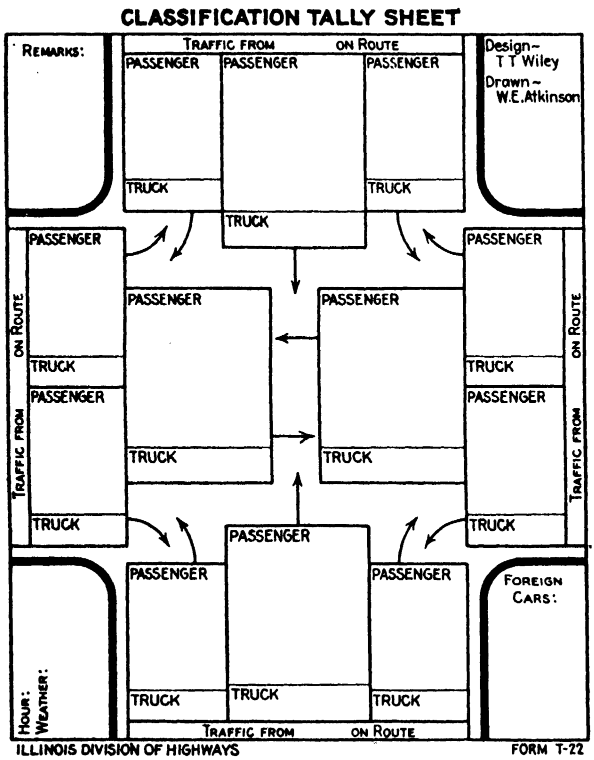


FIG. 17-1.—An excellent form for use in traffic movement surveys.

the nature and size of load carried by trucks, routes traveled, etc. They are usually made by stopping the vehicles and making inquiries of the drivers. They are useful in selecting routes for improvement or providing belts and bypasses, especially in or near large cities.

Belt-line surveys are modified origin-destination surveys to determine the amount and kind of traffic passing directly through an urban center and which, therefore, would probably be benefited by a belt line or bypass. The method indicated above

may be used but the license-time method is probably better, at least for cities of moderate size. Stations on each trunk highway at the edge of the city are chosen and the distance and normal time of travel between them determined. The time of day and license number of each vehicle inbound and outbound past each station are recorded. From these data it is possible to determine the routing of vehicles through the city, the number going through without stops, the number and duration of stops of different lengths of time, and the amount of traffic terminal in the city. This work may be done manually or by means of sorting and tabulating machines. Other facts of social and commercial interest can be derived from the data.

Accident surveys study the number, location, character, cause, and result of accidents on the highways.

Pedestrian surveys are similar to vehicular surveys and when combined with them aid in establishing traffic regulations or help in the designing of streets and sidewalks.

A *traffic map* shows the density, volume, distribution, origin and destination, or other features of traffic in a given area. *Traffic charts* are graphs of various forms showing certain characteristics or features of the traffic.

Several of the states have made, and are continuing, state-wide traffic surveys. A number of cities also have continuous traffic studies under way.

Soil Surveys.—Soil surveys are made for the purpose of determining the kind and location of the different soils that make up the subgrade. Such data may be of great value in making the plans and writing the specifications, especially with regard to earthwork, drainage, and soil treatments.

PLANS AND SPECIFICATIONS

The plans and specifications constitute the written instructions for doing the work. The plans consists of the *plan*, the *profile*, the *cross-sections*, and the *details*. They show graphically the shape, dimensions, and locations of the various parts of the work. The specifications give the necessary written explanations, instructions, and regulations for doing the work. The plans and specifications must supplement and reinforce each other but should avoid unnecessary duplication.

The Plan.—The plan is a map or plat of the horizontal projection of the work. It shows the horizontal alinement, the

limits of the work, the relative position of the various parts, the major dimensions, and such auxiliary information as names of property owners, topographic features which affect the project, etc.

The plan should be drawn to scale. Most road and street pavement plans are made to a scale of 100 ft. to the inch. Occasionally a larger scale is used, especially on city work. For general layout covering a long distance *strip maps* to a scale of about 1 mile to the inch are frequently used.

Practically all of the state highway departments have adopted the *federal aid sheets* for all of their road work. These sheets are required by the U. S. Bureau of Public Roads[1] for all federal aid work. The sheets are 24 by 36 in. and are made in three styles, two for plan-profile work and one for cross-sections. The space for the plan is blank. The profile space is divided to 0.5 in. horizontally and 0.1 in. vertically. The cross-section paper is cross-ruled to 0.1 in. The sheets are obtainable of either tracing paper or tracing linen at reasonable prices. They are to be recommended for all road work. These sheets are also excellent for city pavement work and many cities are using them.

The Profile.—The profile shows the vertical alinement and the relative elevation of all of the various parts or features of the work. It is drawn to the same horizontal scale as the plan and should be placed opposite the plan so that locations are readily transferable one to the other. The vertical scale is exaggerated with respect to the plan. The scale used depends on the change of elevation in the length of a profile sheet. A very common scale is 1 in. equals 10 ft. but scales either double or one-half this size may be desirable.

The Cross-section.—Cross-sections are platted to a suitable scale for the purpose of calculating cut and fill. They must be accurately drawn if a planimeter is to be used. They are usually made to the same scale horizontally and vertically, but different scales may be used. In the first case the planimeter reading is multiplied by the square of the scale ratio and in the latter by the product of the scale ratios. Two very common scales are 10 ft. to the inch and 5 ft. to the inch. A scale of 10 ft. horizontally and 5 ft. vertically is useful for shallow cut and fill work.

[1] *Misc. Circ.* 62, U. S. Dept. Agr.

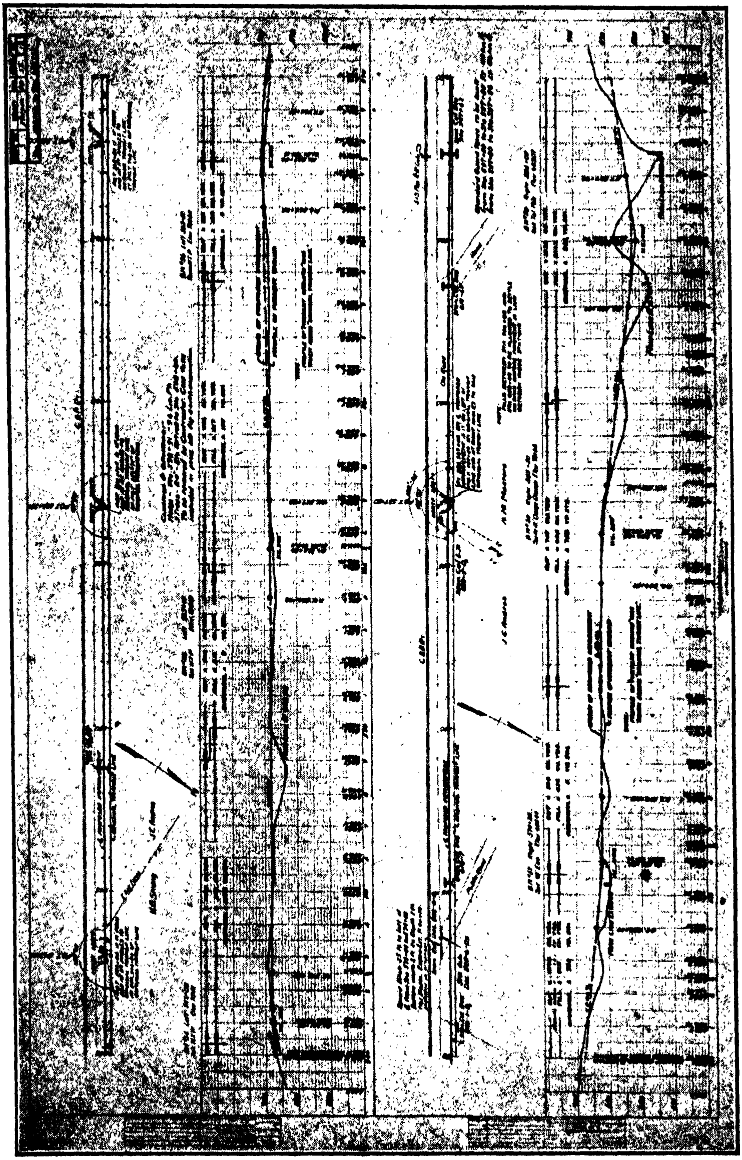


FIG. 17-2.—Typical federal-aid road plans.

The Details.—These drawings show the shape, dimensions, and makeup of all the various individual parts of the work, from the smallest to the largest. These drawings should be made to suitable scales on sheets of the same size as the plan-profile and cross-section sheets.

The Specifications.—Specifications should be clear, concise, complete, and definite. They constitute an engineering document intended to convey to the contractor the ideas of the engineer in regard to manner and requirements of doing the work. In general, dimensions should be omitted from the specifications. It is the function of the drawings to give the dimensions. The drawings and specifications should supplement, not duplicate each other, and together form complete instructions and descriptions for the work.

In general, specifications consist of (1) clauses relating to the general conditions under which the work must be done, including the powers and responsibilities of the various parties and the definition of terms, (2) provisions fixing the kind and quality of the different materials and methods for determining these qualities, (3) instructions for doing the various parts of the work to the required standards, (4) statements as to the standards required, (5) inspection, rejection, and replacement of defective or unsatisfactory parts, (6) method of measurement of the various parts for payment, and (7) special provisions covering any special parts of the work or modifications of usual requirements under unusual conditions.

It must not be forgotten that the plans and specifications are a part of the contract and therefore have a legal significance. They must be complete if they are to serve their purpose. They must be concise if they are to be used under the pressure of construction work. Legal redundancies of language should be strictly avoided and above all they must be clear and definite so that there is no chance for ambiguity. Specification writing is one of the most difficult parts of engineering work and must never be slighted.

ESTIMATES

Estimates are made for determining the cost or value of something and are used for many different purposes. The highway engineer usually thinks of estimates in connection with the cost of highway improvements. The making of an estimate involves

the determination of the quantities or amounts of each of various items which go to make up the whole, and the ascertaining of the unit value of each item, from which the total cost or value can be calculated.

General and Detailed Estimates.—A *general estimate* divides the project into a small number of items and assigns a value to each, although each may be made up of a number of other items. A *detailed estimate* analyzes each item of a general estimate down to the elements which compose it. Thus a general estimate would include a certain number of square yards of pavement at a given price, while a detailed estimate would analyze the cost of the pavement itself as to the amount and cost of each material in it, the labor required, and anything else necessary to make the finished pavement.

Preliminary Estimates.—Preliminary estimates are general estimates made largely for the purpose of establishing the scheme of financing the project. Such estimates should be as accurate as available data will permit but should err in being generous rather than deficient.

Engineers' Estimates.—Engineers' estimates are generally made for the purpose of checking the contractor's bid and for use in financing the work. They lie between the extremes of detailed estimates and the broad generality of the preliminary estimates. They are itemized to the units on which the bids will be received and in accordance with which the contractor will be paid. Sometimes detailed analysis of some of the items will be necessary to establish the unit prices to be used in the estimate.

Contractors' Estimates.—Contractors' estimates are made for the purpose of establishing the prices to be bid. In general, they are more detailed than the engineers' estimates. The stronger the competition and closer the bidding, the more carefully must the contractor analyze the cost of each item, if he is to receive the contract and yet make a profit. Wildcat bidding has resulted in the financial failure of many a contractor, and the awarding of a contract at a price less than one at which the work can be done at a profit adds greatly to the problem of the engineer in securing the quality of work agreed upon.

Progress Estimates.—At periodic intervals during the progress of the work, estimates are made of the amount of work done for the purpose of making partial payments to the contractor. On large contracts such estimates are commonly made each month

ESTIMATE OF COST OF LOCAL IMPROVEMENT

4,300	cu. yd. excavation, including rolling, fine grading, and the removal of waste material, at 70 cts. per cubic yard....	$ 3,010.00
9,880	sq. yd. reinforced-concrete pavement 7 in. thick, including steel reinforcement, asphalt expansion joints, steel plate and dowels for center joint, and steel protection plates, at $2.55 per square yard....................	25,194.00
5,840	lin. ft. combined concrete curb-and-gutter, consisting of a curb 6 in. thick and 13 in. deep and a gutter flag 6 in. deep and 18 in. wide set on a 3-in. cinder foundation, complete in place, including steel dowels and asphalt expansion joints, at 85 cts. per lineal foot............	4,964.00
80	lin. ft. 27-in. vitrified clay pipe drain, complete in place, including trenching, laying, backfilling, and the removal of waste material, average depth 7.5 ft., at $3.50 per lineal foot..	280.00
384	lin. ft. 18-in. vitrified clay pipe drain, complete in place, including trenching, laying, backfilling, and the removal of waste material, average depth 7.5 ft., at $1.80 per lineal foot..	691.20
470	lin. ft. 15-in. vitrified clay pipe drain complete in place, including trenching, laying, backfilling, and the removal of waste material, average depth 6.5 ft., at $1.10 per lineal foot..	517.00
1,050	lin. ft. 15-in. vitrified clay pipe drain complete in place, including trenching, laying, backfilling, and the removal of waste material, average depth 7.5 ft., at $1.60 per lineal foot..	1,680.00
500	lin. ft. 10-in. vitrified clay pipe drain complete in place, including trenching, laying, backfilling, and the removal of waste material, average depth 7.0 ft., at $1.10 per lineal foot..	550.00
1,610	lin. ft. 8-in. vitrified clay pipe drain, complete in place, including trenching, laying, backfilling, and the removal of waste material, average depth 7.0 ft., at 90 cts. per lineal foot..	1,449.00
9	manholes 3.5 ft. inside diameter, the walls to be of brick, 8 in. thick, complete in place, including cast-iron cover and lid, total depth 105 ft., at $9.00 per foot of depth..	945.00
13	curb inlets complete in place, including curb bar, concrete curb over inlet, concrete foundation and 10-in. tile elbow, at $35 each..............................	455.00
	Cost of engineering services........................	1,310.80
	Cost of making and collecting special assessments, including court costs...........................	2,619.00
	Total..	$43,665.00

FIG. 17-3.—City engineer's estimate.

and hence are frequently termed *monthly estimates.* These are officially made by the engineer in charge but the contractor frequently and legitimately makes similar estimates as a check, and for his protection.

At each monthly estimate, measurements are made to determine the total amount of each item of the improvement completed to date. From the total value of this work at the bid prices is subtracted the total value of the previous estimate. The remainder is the amount due the contractor. From 10 to 15 percent of the amount is normally retained as a guarantee of the continuance of the work and also as a fund to cover errors and contingencies. The amount paid is called a *partial* or *monthly* payment.

At the completion of the contract a *final estimate* is made from careful measurements. The total cost of the project as actually built, less the amounts previously paid, and any deduction for cause constitutes the *final payment.*

Quantities.—The quantities for preliminary estimates are obtained from the best available sources such as maps and reconnaissance surveys. Engineers' and contractors' estimates are made from the dimensions and other data included in the plans and specifications. The engineer has had the advantage of going over the ground and the careful bidder should also examine the site in the field. Progress and final estimates are made from measurements of the actual work.

Unit Prices.—The establishing of unit prices is the most difficult part of estimating. Prices of materials can be readily obtained. Labor costs are more indefinite. Contingencies, or the risks of doing the work, are the hardest to forecast and must be carefully considered. Following these are items of incidental expenses, overhead costs, and profit. The engineer's estimate, also, must often include items of cost for legal, engineering, and financing expenses.

In general, the contractor possesses the best records of actual costs of materials and labor and therefore can estimate the cost in detail. The engineer usually bases his unit prices on previous bid prices modified by fluctuations in prices of labor and material. Occasionally some entirely new feature is added to the work. In this case the engineer may make his estimate of its cost and as a check ask some reliable contractor to submit an estimate. In this way both sides are given a chance to consider the pro-

COST ESTIMATE OF ONE-COURSE CONCRETE PAVEMENT

City............County............State...........Date............
Name of project or street.......................................
Width of pavement..........Square yards......Average thickness......
Mix: cement..........Fine aggregate..........Coarse aggregate.......

		Gravel or	
Weights of aggregates per cubic yard: sand........		pebbles....	stone......

		Handling and hauling	Cost per cubic yard
Cement per barrel f.o.b. destination...	$........	$........	$........
Fine aggregate per cubic yard f.o.b. destination........................	$........	$........	$........
Coarse aggregate per cubic yard f.o.b. destination......................	$........	$........	$........

Multiple...................... (average thickness divided by 36)

Material Factors

	Cost per square yard of pavement
Cement........Barrels per cubic yard at $......per barrel.	$..........
Fine aggregate......Cubic yards at $......per cubic yard..	$..........
Coarse aggregate.....cubic yards at $......per cubic yard.	$..........
Add 5 percent to aggregates for loss......................	$..........
Weight of reinforcing per 100 sq. ft......................	$..........
Lineal feet of joint filler.............at $..per lineal foot..	$..........
Fuel and oil..	$..........
Water (50 gal. per square yard) at $....per 1,000 gal.......	$..........
Material total..	$..........
Labor Factor	
Labor: constructing slab complete.........................	$..........
Total for material and labor..............................	$..........
............sq. yd. at $..................................	$..........
General Factors	
Contractor's profit, overhead, and contingencies at..........	$..........
Cost of moving equipment (freight, labor, etc.)............	$..........
Depreciation and maintenance of equipment..............	$..........
Cost of contract bond at $......per $1,000 of contract......	$..........
Employer's liability insurance at $......per $100 of payroll.	$..........
Employer's public insurance at $.... per $100 of payroll....	$..........
Net bid...	$..........
Adjustment for market value of bonds $....	$..........
............sq. yd. at $............per square yard......	$..........

This estimate based on the placing of . . . sq. yd. per day.

FIG. 17-4.—Typical form of contractor's estimate.

posed item and the estimate of its cost is likely to be more nearly correct than if one party only makes the estimate.

Loading Estimates.—In some states the local improvement laws are so framed that the engineer's estimate on which the assessment is made cannot include certain items, such as contingencies and interest deficiency on the bonds. The custom has therefore arisen of loading the estimate to supply the necessary funds. This is not so much an evasion of the law as the supplementing of law and is connived at by the courts themselves. The contractor is aware of this practice of loading and makes his bid accordingly. He knows that the actual work is less than that shown in the estimate but he also knows that there are funds to cover unforeseen difficulties, changes, etc., which frequently occur and for which he may be entitled to extra compensation.

The loading is accomplished by increasing the quantities of certain items. Thus excavation is usually not modified and the number of inlets, etc., must agree with the plans. The total depth of manholes and catch basins can be increased and pavement and tile quantities increased 2 to 5 percent. The loading should never be done by increasing the unit prices, since this might tend to defeat the very purpose for which the loading is done and also might tend to increase the prices above their normal level.

Problems

17-1. Prepare forms like Fig. 17-1 (they can be mimeographed) and make a traffic count of an assigned intersection, changing sheets every half hour for a period preferably not less than 3 hr.

17-2. Make a chart showing the traffic variation by half-hour intervals from the data obtained in Prob. 17-1.

17-3. Make a minute-by-minute record of the traffic in each direction for a period of at least an hour on a busy street or highway at a point between intersections.

17-4. Make a flow chart from the data obtained in Prob. 17-3 showing the minute-by-minute variation in each direction and also the total in both directions.

17-5. Prepare an estimate form similar to Fig. 17-4 for a vertical-fiber brick pavement with surface removal asphalt filler, asphalt mastic cushion, and concrete base.

17-6. Prepare an estimate form similar to Fig. 17-4 for a sheet asphalt or asphalt concrete pavement on concrete base.

17-7. Prepare an estimate form similar to Fig. 17-4 for an asphalt macadam surface on a waterbound macadam base.

17-8. A monthly estimate shows figures for the first column in Fig. 17-3 as 4,020, 7,870, 5,160, 80, 384, 470, 880, 260, 1,320, 8 with a total depth of 82 ft. and 9, respectively. The contract was let for the quantities and prices shown in Fig. 17-3 and the contractor has been paid $7,692.66 on previous estimates. Determine the net amount due the contractor if 15 percent is to be retained as a guarantee.

CHAPTER 18

COMPARISON OF ROADWAYS

The value of a highway must always be estimated in terms of the service it renders. If the service rendered is not commensurate with the expense entailed the road should be abandoned. If the service capable of being rendered by an improvement is greater than the costs involved, the additional expense is justified.

The benefits conferred by a highway are of two kinds. First, *tangible returns* in the form of decreased transportation costs which can be evaluated in money. Second, *intangible returns* in the form of comfort, convenience, cleanliness, continuity of service, etc., which rarely can be assigned money values. Highway economists have given almost undivided attention to the tangible items of cost and have neglected the intangible benefits. In the ultimate analysis it would not be surprising to find that the intangibles are the fundamental reason for all road improvement and that reduced costs of transportation are of importance merely because they help to pay the bill.

No matter what type of road is built it must be paid for and its cost must be kept within the ability of the people to pay. Relative costs, therefore, form a primary basis of comparison for different kinds of roads. But costs are never considered alone. They are always combined with other factors in which the intangibles take a prominent if not dominating part.[1]

COSTS

The total cost of highway transportation may be divided into two parts, *viz.*, roadway costs and vehicular costs. Each of these is made up of several items, all of which must be evaluated to find the total cost.

Right-of-way.—Since highways are absolutely essential to human needs it might well be claimed that the land occupied by public roads is a public necessity and need not be assigned a value.

[1] Intangible Economics of Highway Transportation, *Proc.*, Thirteenth Ann. Meeting, Highway Research Board, Pt. I, p. 189, 1933.

On the other hand, most right-of-way is merely an easement, the actual title remaining with the adjoining lands. Hence it may be argued that the right-of-way should have the same value as the lands of which they are a part. Furthermore new right-of-way must often be acquired, frequently at very high prices, but in a sense this is merely an added item of first cost of the improvement.

In any case right-of-way is the one item that approaches permanency; hence its annual cost is small since the total is spread over a long period of time. Furthermore the right-of-way is generally the same irrespective of the type of surface and therefore can be omitted in making comparisons of cost.

Grading and Draining Costs.—The right-of-way must be graded and drained to make it usable. The cost of this work ranges from $50 per mile in the soft level prairies to $50,000 or more per mile in mountainous country. This work, however, is semipermanent in character; hence the annual cost becomes very small. Moreover, these grading and drainage costs are practically independent of the type of surface; hence they can be omitted from comparisons of surfacing costs. Comparisons of grading costs, such as grade reductions as given in Chap. 15, are made separately from the surfacing.

First Cost of Surface.—The first cost is an important item in the scheme of financing, and in making comparisons of different roadways. The first cost must always be considered in conjunction with maintenance costs and the traffic capacity of the particular surface. Unfortunately there is a popular tendency to overemphasize low first cost and not give due consideration to the importance of maintenance and capacity. On the other hand, it is sometimes expedient to choose surfaces of low first cost either because available funds are inadequate to buy a really economic surface or to serve temporarily until a high-grade improvement can be installed.

Table 18-1 gives the approximate range of first costs of various types of surfaces and the ordinary maximum economic traffic capacity. A type of road whose capacity is well above the probable traffic should, if possible, always be employed.

Maintenance Costs.—Maintenance costs share with first cost the greatest importance in highway finance. Not only do they affect the annual cost and economic life but they must be given consideration in any adequate scheme of finance. It is not suffi-

cient to provide funds only for construction. The maintenance program must receive proper support.

In general, maintenance costs increase with the age of the work and at an increasing rate. Fluctuations, however, occur owing to discontinuity in the maintenance program and the variations in current prices of labor and material. Data to determine the variation with age are very meager. Statistics are many but they have not been correlated. In addition, many factors affect the

TABLE 18-1.—FIRST COST AND TRAFFIC CAPACITY OF DIFFERENT ROAD SURFACES

Kind of surface	First cost, exclusive of grading and draining, dollars		Economic traffic capacity of double-track road vehicles per day
	Per square yard	Per mile 20 ft. wide	
Earth	0.01 to 0.02	100 to 250	100 to 200
Oiled earth	0.03 to 0.08	400 to 1,000	200 to 300
Sand clay	0.10 to 0.12	1,000 to 1,400	200 to 300
Gravel	0.10 to 0.80	1,000 to 10,000	300 to 600
Macadam	0.50 to 1.25	5,000 to 15,000	300 to 600
Bituminous carpets, etc.	0.08 to 0.20	800 to 2,400	500 to 1,000
Bituminous macadam	1.25 to 1.75	13,000 to 21,000	800 to 1,200
Bituminous concrete	2.00 to 3.00	23,000 to 35,000	2,000 to 4,000
Sheet asphalt	2.50 to 4.00	29,000 to 47,000	2,000 to 4,000
Wood block	4.50 to 8.00	47,000 to 85,000	Limited by width
Granite block	5.00 to 10.00	52,000 to 100,000	Limited by width
Brick	3.50 to 5.00	37,000 to 50,000	Limited by width
Concrete	1.50 to 2.75	18,000 to 32,000	Limited by width

maintenance costs and it is hard to separate those due to age. Maintenance costs also increase with the traffic weight and density. Here again few reliable data are available. Moreover, both traffic density and standards of construction have developed so rapidly that conclusions reached a few years ago are now only roughly applicable. Likewise, recent records cover too short a period to yield accurate information of the kind needed.

The city of Buffalo[1] in 1916 reported some data and conclusions which have been frequently cited and which are typical of the

[1] *Twenty-fourth Ann. Rept.*, Bur. Eng. City of Buffalo, 1916.

information required. Other cities and several of the state highway departments have collected a large volume of information and statistics but so far the material has not been correlated and made public. Thus, despite the importance of maintenance costs, very few usable data are available.

Salvage Value.—The salvage value is the value which can be realized from the old surface or pavement at the time of renewal. This may be purely a junk value such as the price secured from the sale of the materials removed. Again, it may be the value at the time of replacement of any materials, or integral parts, of the old roadway which are incorporated in the new work.

In case a definite part of an old pavement, such as a concrete base, is used in the new work, its salvage value should be taken as the cost of a new base at the current price, less the amount required to put the old base into as good or as serviceable condition as that of a new base.

The salvage value may become negative. This will occur when it costs more to put the part to be salvaged into satisfactory condition than it does to lay an entirely new part. It also occurs when it costs more to remove the old pavement than to make equivalent earth excavation.

The salvage value is not constant. It tends constantly to decrease but fluctuates with variations in current prices. It is sometimes assumed that the salvage value reaches a minimum at the economic life and need not be further considered. This is not correct. The salvage value continues to decrease beyond this life, thus adding to the annual expense and increasing the loss due to not renewing the pavement at the end of its economic life.

The salvage value is generally overestimated. Often the condition of the portion salvaged is so far below the quality of new work that there is an economic loss despite an apparent financial gain. Furthermore, general defects, such as those in drainage, grades, or crown, may be carried over into the new work resulting in both tangible and intangible losses greater than the apparent saving.

Average Annual Cost.—The average annual costs form a convenient and reliable method of comparing the tangible roadway costs of different types of improvement.

Since governmental units are organizations not for profit; since taxes are invariably charged off as expenses; and since public bodies are not permitted to accumulate funds for future

work, it would seem that the average annual cost should be based entirely on the actual sums paid out. On this assumption

$$C = \frac{I + i + M - S}{N} \tag{18-1}$$

where C is the actual average annual cost, I is the total initial cost including administration, financing, engineering, construction, extras, etc., i is the total interest actually paid on bonds or loans, M is the total actual maintenance and repair costs including supervision, engineering, etc., S is the salvage value, and N is the age of the pavement in years.

Some writers maintain that the time value of money must be considered. On this basis

$$C = Ir + \frac{(I - S)r}{(1 + r)N - 1} + m + \frac{E'r}{(1 + r)N' - 1)} + \frac{E''r}{(1 + r)N'' - 1} \tag{18-2}$$

where C, I, S, and N are the same as before, m is the annual maintenance, r is the rate of interest the funds are assumed to be capable of earning, while E' and E'' are the annuities to finance the costs of specific repairs made at the intervals of N' and N'' years, respectively.

The costs obtained by this formula are fictitious, *i.e.*, do not actually exist in money, and therefore cannot be checked against the recorded receipts and expenditures. This is likely to be viewed with suspicion by the average citizen. The figures, too, are likely to be misleading since they are higher than those recorded and therefore may result in the conclusion that a proposed improvement cannot be financed when in fact it can.

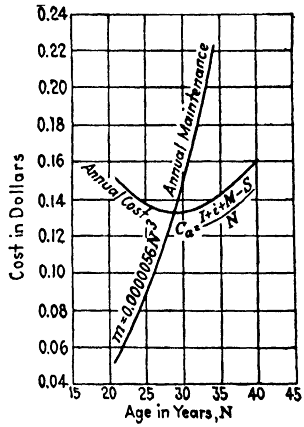


FIG. 18-1.—Determination of economic life of asphalt pavement.

The annual costs of a given pavement computed by Eq. 18-1 may be considerably different from that computed by Eq. 18-2. The *relative* costs of different pavements, however, will not be greatly different if the same equation is used for all. Consequently the investigator may use the one that appeals to him. He should keep in mind, however, that these formulas make use

of data subject to considerable variation and therefore the results have a high probable error. There is altogether too much of a tendency to consider such computations as law.

Economic Life.—The economic life is the age at which maintenance costs have become so great as to justify renewal. It is the age at which the average annual cost is a minimum.

The economic life can be determined by finding when the annual cost C becomes a minimum. If the various terms in Eq. 18-1 follow mathematical laws it is possible to determine the economic life by means of the calculus. It is simpler and quicker, however, to do it graphically and this method has the advantage that irregular variations in any of the terms can be included. The values of C for several values of N, using corresponding values of the other terms, are determined and platted to a convenient scale. The minimum point can then be estimated from the graph with all necessary accuracy. The economic life, however, is also the age at which the annual maintenance cost equals the average annual cost. The curve of annual maintenance can, therefore, also be platted and its intersection with the average annual cost curve gives the economic life.

Example.—Assume the initial cost of a sheet asphalt pavement to be \$3, its salvage value between 20 and 30 years of age to be \$1.10, the interest to be on 10-year serial bonds at 6 percent, and the annual maintenance cost to follow the experience of Buffalo, previously mentioned, and to be given in dollars by the equation $m = 0.0000056N^3$. The total maintenance at any time is $M = 0.0000014N^4$. Taking values of N of 20, 25, 30, and 35 years and solving Eq. 18-1, the corresponding values of C are 0.155, 0.138, 0.134, and 0.142, respectively. The curve (Fig. 18-1) shows that the minimum is somewhere between 28 and 30 years. Platting the curve of annual maintenance it intersects the curve of annual cost at 29 years, which is the economic life.

The economic life can also be determined in a similar manner from Eq. 18-2. Since this equation gives the sinking fund calculated from the same items as used in Eq. 18-1, it should reach a minimum at approximately the same time and therefore the value of the economic life should not be greatly different.

Actual Life.—The actual life of a pavement is the age at which it is actually replaced. This may be either greater or less than the economic life.

If the actual life is less than the economic life it may indicate (1) that the calculated economic life was incorrect, (2) that the

work was defective or improperly maintained, (3) that the traffic was greater than the pavement could carry with all the maintenance adapted to it, or (4) that the pavement was renewed for other than economic reasons. Any or all of these conditions may apply.

The actual life may be greater than the economic life because (1) the pavement is simply not renewed but is continued in service, although at an increasing cost of maintenance, (2) the computed economic life was incorrect, (3) changed conditions such as a well-paved parallel route have acted to extend its useful life.

Economic Life and Bond Issues.—The computation of the economic life forms a basis of estimating the economic term of bonds. No bonds should run longer than the economic life because this would carry over part of the interest cost into the new work. The term of the bonds should therefore be something less than the computed economic life. The more accurately the life can be computed, the more nearly the term can be made to approach it. It is doubtful if it is safe to make the term longer than approximately 0.8 the economic life, and in many cases 0.6 would be safer. Thus if the estimated economic life is 30 years the bond term should not exceed about 25 years and preferably not more than 20 years.

Vehicular Costs.—Vehicular costs include a considerable number of different items. Part of these are fixed or overhead charges independent of the distance the machine travels. The remainder are operating costs that are practically proportional to the distance traveled. Naturally these costs vary over an extremely wide range on account of the many kinds of cars and different operating conditions. Only broad averages, therefore, can be used in general economic studies from which it is customary to reduce the total vehicular costs to a cost per mile.

T. R. Agg from the analysis of a large number of automobile cost records[1] arrives at the average values shown in Table 18-2.[2] He arrives at the further conclusion that for small changes of distance, such as those on account of relocations and

[1] Operating Cost Statistics of Automobiles and Trucks, *Bull.* 91, Iowa Eng. Expt. Sta., Ames, Iowa, 1928.

[2] Estimating the Economic Value of Proposed Highway Expenditures, *Trans.*, A.S.C.E., Vol. 99, p. 1124, 1934.

grade reductions, the cost for the average car is about 2.5 cts. per mile on high-type surfaces and 3.3 cts. per mile on intermediate types. These values are satisfactory for estimating the relative vehicular costs on different roadways.

TABLE 18-2.—RELATIVE COST OF OPERATING AN IMAGINARY AVERAGE AUTOMOBILE ON VARIOUS CLASSES OF ROADS

Item of cost	Approximate relative cost of operation, cents per mile		
	High-type roads	Intermediate-type roads	Low-type roads
Gasoline	1.09	1.31	1.61
Oil	0.22	0.22	0.22
Tires and tubes	0.29	0.64	0.84
Maintenance	1.43	1.72	2.11
Depreciation	1.26	1.39	1.57
License	0.14	0.14	0.14
Garage at $4 per month	0.44	0.44	0.44
Interest at 6 percent	0.36	0.36	0.36
Insurance	0.21	0.21	0.21
Total cost	5 44	6.43	7.50
Relative cost	1.00	1.18	1.38

Permissible Expenditure.—The total cost of highway transportation on a given road is

$$C_t = C_r + C_v - c \tag{18-3}$$

where C_t is the total relative cost, C_r is the relative roadway cost, C_v is the relative vehicular cost, and c is any contribution by the vehicle to the road funds, all per vehicle mile.

The annual saving in cost of transportation made by an improvement is

$$S = (C_1 - C_2) \times T \tag{18-4}$$

where C_1 and C_2 are values of C_t for the respective roads and T is the total annual traffic in vehicle-miles over the given section of road.

The permissible expenditure P is taken as the sum that can be financed by the saving S. This neglects any expenditure justified by the intangible benefits of the improvement. The value of P

may be computed from Eq. 15-16, Eq. 15-17, or Eq. 15-18, whichever seems the most suitable.

GENERAL BENEFITS

Smoothness.—The popular criterion of a modern roadway is smoothness. No matter how substantial or how durable a roadway is, it is condemned if it does not possess at least a fair degree of smoothness. The demand for smoothness is so great that pavements have been replaced which have far from reached their economic life.

Smoothness may be defined as the property of not imparting disagreeable jars to the occupants of motor vehicles. Even this is subject to different interpretations. Thus a concrete pavement is often called smooth because its surface is fine grained, whereas it may actually possess waves and irregularities which give sudden and possibly severe bumps to traffic. At the same time a brick pavement may be called rough because the joints are irregular and yet the surface as a whole may be so even and free from waves that an automobile will glide along almost without a bounce. The degree of smoothness usually required by specifications is that the surface shall not depart more than ⅛ in. from a 10-ft. straightedge when placed parallel with the line of traffic. This smoothness can be easily obtained with any of the modern pavements.

Smoothness has a money value. It has been shown that the tractive resistance and fuel consumption are less on a smooth surface than on a rougher one of the same kind.[1] Experiments by the U. S. Bureau of Public Roads, the Illinois Division of Highways, and others show that rough surfaces add to impact stresses in roadway and vehicles, causing damage to both. The saving due to decreased fuel cost and to lower repairs to road and vehicle would justify considerable expenditure for increased smoothness, but so far this has not been fully evaluated.

Wood block can probably be made the smoothest with the least trouble, closely followed by brick and concrete. Bituminous surfaces are often decidedly wavy and only their high resilience saves them from severe condemnation for roughness. Gravel can be made smoother than macadam, while oiled earth will retain its smoothness better than untreated earth.

[1] *Bull.* 67, Iowa Eng. Expt. Sta., Ames, Iowa, 1924.

Resilience.—Resilience is the property that permits the pavement to absorb minor shocks. Resilience is closely related to smoothness in the effect on traffic. Thus resilience may obliterate the effect of a bump that would be objectionable on a nonresilient surface.

Concrete and monolithic brick are lowest in resilience. Every irregularity must be absorbed by the vehicle. In fact one of the chief objections to concrete is its *harshness* due to lack of resilience. Wood block possesses high resilience and asphalt or sand-filled brick, on a sand or mastic cushion, has a fair degree. Bituminous pavements have high resilience, except in cold weather, as does earth in normal condition. Macadam is poorer than gravel in this respect.

Dustlessness.—Dustlessness is an important element in convenience and sanitation. This quality alone often causes the paving of streets, and the surface treatment of gravel and macadam. The road surface that generates no dust of its own and does not collect dust is the most desirable, whether for city streets or rural roads. Bituminous surfaces, concrete, grout-filled brick, wood block, etc., all possess a high degree of dustlessness. Open-jointed, sand-filled brick and stone block collect dust. Earth, gravel, and macadam, when oiled, have the dust nuisance more or less mitigated, but these same roads when untreated are often intolerably dusty. Probably limestone macadam is the worst.

Noiselessness.—Formerly, noiselessness was considered of great importance. The universal use of pneumatic tires has largely eliminated the wheel noise, the absence of horses has done away with the clatter of their shod feet, and the automobile or truck possesses fewer loose parts to rattle than did the wagon. Substituted for these noises, however, is the swish of the tires on the pavement, the hum of the machinery, the purr of the exhaust, and the noise of horns, all of which combine into the roar of modern traffic. These noises, themselves, are practically independent of the type of pavement, but the pavement has a great deal to do with their reflection and concentration. Plastic and resilient surfaces are the most desirable from the standpoint of quietness while the rigid types, like grouted brick or concrete, are the most objectionable. Streetcars are especially noisy on concrete or grouted brick streets, but a bituminous carpet will diminish the reflection of the sound.

Color.—Color may exert considerable influence on the choice of the surface. Light-colored surfaces like concrete and macadam have the advantages of high visibility at night and low heat absorption. On the other hand, they may have a disagreeable glare in bright sunshine. The dark-colored surfaces like asphalt and wood block tend to absorb heat and become unduly warm. They have low visibility but are free from glare. Color may also have an esthetic value on account of its relationship to the landscape. Thus the pale salmon color of novaculite gravel is very pleasing and the red of certain paving brick harmonizes with the usual street colors. The city of San Francisco chose brick for certain of its streets on account of the color.

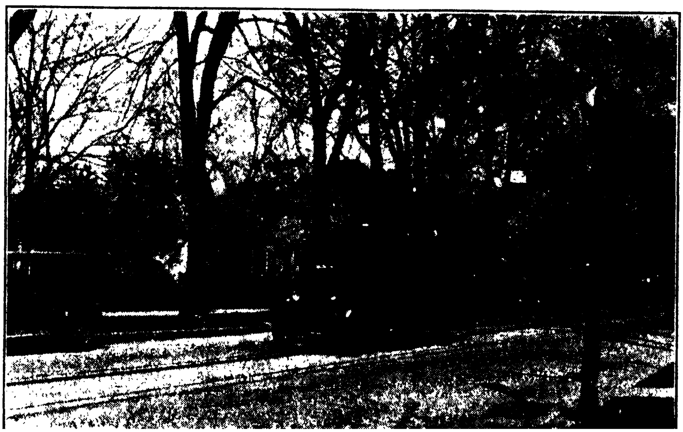


FIG. 18-2.—A concrete pavement with solid track construction caused the substitution of busses for street cars on this street to reduce the noise.

Slipperiness.—Adequate foothold for horses was formerly an important surface characteristic. At present, sufficient friction between the wheels of motor vehicles and the surface must exist to develop tractive effort, braking power, steerage way, and to overcome side thrust. If the surface is deficient in adhesion, *i.e.*, is slippery, there may be insufficient traction to propel the vehicle but more generally the vehicle *skids* or slides. It is then out of control and may collide with other vehicles or objects or leave the roadway with possibly disastrous results.

When dry, all roadways have ample resistance to skidding and there is not a great deal of difference between the various kinds

of surfaces.[1] As the surfaces become wet the *antiskid factor*, or coefficient of friction f, decreases. In some cases the decrease is very marked. A thin film of mud produces a great tendency to skid. When the surface is covered with an appreciable thickness of mud, snow, ice, etc., the coefficient of friction is that of

TABLE 18-3.—APPROXIMATE VALUES OF THE COEFFICIENT OF FRICTION BETWEEN RUBBER TIRES AND ROAD SURFACE

Kind of surface	Coefficient of friction			
	Straight skid		Side skid	
	Dry	Wet	Dry	Wet
Bituminous (hard)	0.75	0.50	0.85	0.55
Bituminous (soft)	0.75	0.35	0.85	0.40
Brick (bare)	0.75	0.50	0.85	0.55
Concrete	0.80	0.50	0.90	0.60
Earth (compact)	0.60	0.20	0.65	0.25
Earth (oiled)	0.65	0.35	0.70	0.40
Gravel and macadam	0.60	0.60	0.65	0.65
Ice and sleet (hard)	0.10	0.10	0.10	0.10
Ice (cindered)	0.30	0.30	0.35	0.35
Ice (tire chains)	0.30	0.30	0.35	0.35
Snow (packed)	0.35	0.35	0.35	0.35
Snow (thin on ice)	0.10	0.10	0.12	0.12
Stone block	0.75	0.45	0.80	0.50
Wood block	0.75	0.40	0.80	0.45

the covering and not of the pavement. The coefficients of friction vary over a wide range on account of the many varieties of tires, road surfaces, and driving conditions. Table 18-3 gives approximate values suitable for ordinary use.

The antiskid characteristics play an important part in highway safety, since the distance in which a car can stop from any speed depends on the coefficient of friction of the wheels with the road surface and the ability of the brakes to utilize the friction. Table 18-4[2] shows safe speeds on different types of surfaces for four-wheel brakes in good condition.

[1] Skidding Characteristics of Automobile Tires on Roadway Surfaces and Their Relation to Highway Safety, *Bull.* 120, Iowa Eng. Expt. Sta., Ames, Iowa, 1934.

[2] From *Bull.* 120, Iowa Eng. Expt. Sta., Ames, Iowa.

Choice of Surface.—The proper choice of surface demands a careful consideration of all the foregoing factors, both economic and general. Rarely, however, is it possible so to correlate the

TABLE 18-4.—MAXIMUM SAFE SPEEDS FOR TYPICAL STOPPING DISTANCES IN URBAN AND RURAL AREAS FOR TYPICAL SURFACE CONDITIONS

Area	Stopping distance, feet	Initial speed, miles per hour when stopping distance equals braking distance				Initial speed, miles per hour, when stopping distance equals reaction time distance plus braking distance[1]			
		Dry surface, $f = 0.8$	Average surface, $f = 0.5$	Snow or mud, $f = 0.2$	Ice, $f = 0.1$	Dry surface, $f = 0.8$	Average surface, $f = 0.5$	Snow or mud, $f = 0.2$	Ice, $f = 0.1$
Urban	20	22	17	11	8	15	13	9	7
	50	35	27	17	12	27	22	15	11
	100	29	39	24	17	41	34	22	16
Rural	250	77	61	39	27	69	56	37	26
	500	110	87	55	39	101	81	53	38

[1] Reaction time taken as 0.5 sec.

TABLE 18-5.—COMPARISON OF GENERAL CHARACTERISTICS OF ROADWAY SURFACES

Kind of surface	Relative rank of surfaces according to sanitary and convenience qualities							
	Smoothness	Resilience	Dustlessness	Ease of cleaning	Noiselessness	Color	Heat absorption	Skid
Concrete	3	11	5	2	9	3	1	1
Grouted brick and stone block	4	10	6	3	10	2	3	4
Brick (bare)	2	5	4	4	6	1	5	3
Stone block (bare)	11	9	8	7	11	4	4	7
Wood block	1	3	1	5	2	8	6	10
Sheet asphalt and bituminous concrete	5	6	2	1	3	9	11	2
Bituminous macadam and carpets	6	4	3	6	4	10	10	6
Macadam	10	8	11	9	8	6	2	5
Gravel	7	7	9	10	7	5	8	8
Oiled earth	8	1	7	8	1	11	9	9
Firm earth	9	2	10	11	5	7	7	11

factors that it can be positively said that one certain type is definitely superior to all others. A careful consideration of these factors shows that *there is no such thing as a single uni-*

versally best surface. After a careful study of all available types it will usually appear that any of two or three are approximately equal in value for a given location. The one should then be chosen which can be most easily financed, is the easiest to supervise and construct, or is most pleasing and acceptable to the adjoining residents.

Problems

18-1. A concrete road slab cost $1,050 per mile per foot of width. Bonds were issued on which the total interest was 42 percent of the principal. The salvage value was to be taken as zero at any time after 20 years. The total maintenance cost $M = \$4N^{1.1}$. What is the average annual cost by Eq. (18-1) for ages of twenty, twenty-five, and thirty years?

18-2. A sheet asphalt pavement cost $3 per square yard, of which $1.25 was for the concrete base which can be salvaged at 90 percent of its cost. If the total maintenance is $M = 4N^{1.2}$ cts. per square yard, what is the economic life?

18-3. A gravel road is estimated to be costing traffic 6½ cts. per car-mile which can be reduced to 6 cts. by a Wisconsin treatment. If the annual traffic is 75,000 vehicles, what is the maximum amount of 5 percent 5-year serial bonds that can be financed from the saving? Would this be sufficient (see Chap. 11)?

18-4. A gravel road cost $3,000 per mile and at the end of 30 years has a salvage value of zero. The annual maintenance cost is $150 per mile in addition to which partial rebuilding must be done every 6 years at a cost of $800. What is the annual cost by Eq. 18-2?

18-5. A curve has a radius of 350 ft. and no superelevation. If the coefficient of friction for lateral skidding is 0.55, what is the theoretical speed that will cause skidding, assuming equal weight on all wheels? If the coefficient is 0.20?

18-6. If the road in Prob. 18-5 is superelevated 0.06 ft. per foot, what would be the speeds for skidding, other factors being the same?

18-7. In a locality subject to frequent sleet storms what should be the maximum grade on a main road?

CHAPTER 19

FINANCE

The raising of necessary funds is always coincident with engineering projects. Sometimes it falls to the lot of the engineer to have an active part in the financing. Sometimes the financing is entirely outside his activities. In every case, however, he is vitally interested since the amount of available funds, their source, and the method of obtaining them often have a direct and material influence on his work. Too often, the engineer is inclined to leave the financing to others. In road and pavement work he is almost certain to be compelled to take an active part in the financing and, therefore, he should take every opportunity to become informed on the subject.

Public roads and streets are built by governmental units. Therefore, the problem of financing them is one of public finance or *taxation.*

TAXES

Taxes are the contributions required from the individual to finance the work of the government.

Direct taxes are those levied directly on the individual, such as property taxes, license fees, and income tax. *Indirect taxes* are those paid directly by a manufacturer or dealer but passed on by him to the individual in the form of increased prices. Import duties, excise taxes, internal revenue, etc., are examples. The federal government is financed principally by indirect taxes, while local units use direct taxation. The latter are therefore the most important to the road builder, although the former are of interest through federal aid.

Taxes fluctuate with the prices of commodities and labor, and also with the intensity of governmental activity. Political units must pay the same prices for materials and labor as anyone else. Therefore, when prices are high, taxes must increase, or else the public activities must be reduced because of inadequate revenue. In periods of financial depression there is a corresponding tend-

ency for taxes to decrease. On the other hand, there is a tendency for taxes constantly to increase owing to an ever-present and insistent demand on the part of the people for the government to take on additional duties. There are those who would have us believe that the government is reaching out and trying to usurp private enterprises. The fact is that the government is always loath to take on additional duties. As civilization advances it is found that there are more and more things of benefit to all that the government can do better than can be done individually. If, therefore, the people demand that their government do a certain thing they must be ready to pay the added cost in increased taxes. The return is either in greater economy, better service, or in new service. Thus the people have demanded better roads. Consequently they are paying increased road taxes but, in return, are receiving unprecedented road service.

Road and street work are financed primarily by poll tax, general property tax, vehicle and driver license fees, fuel tax, and special assessments. Minor sources of revenue such as gifts and tolls are occasionally available.

Poll Tax.—Poll tax is a per capita tax and generally ranges from $1 to $5 per annum. In some localities its payment is prerequisite to voting. It is used almost invariably for local roads and formerly was often payable in labor. It never was popular and was often difficult to collect; hence its use is decreasing.

General Property Tax.—The general property tax is levied against the real and personal property of the individual in ratio to its value. The value used for taxation is known as the *assessed value*. The amount of tax per unit of assessed value is the *tax rate* and is given in mills per dollar or dollars per $100.

Since the product of the assessed value and the tax rate must equal the required tax, it is evident that taxes cannot be compared by the tax rate unless the method of assessing is the same. In some states the assessed value is the market value and in others some arbitrary fraction of the market value. Therefore, the comparison of taxes or property values by the assessed value is not possible unless reduced to a uniform basis.

The general property tax is the basic tax in this country. Each political unit has certain taxing powers. Each, however, is limited in its levy and this is known as the *tax limit*. It can be exceeded only by vote of the people directly affected. The

total tax on any property is the sum of all these separate taxes.

Vehicle License Fees.—The vehicle license fee originated purely as a registration fee to cover the cost of keeping a record of the vehicles, especially the automobile. With the increase in the number of motor cars it soon became evident that it was a fruitful source of revenue, and the rates were modified accordingly.

The automobile license fee has all the requirements of a good tax. The need of funds is evident. It can be made reasonably equitable, is easily collected, and is acceptable to the public. In general, the automobile license is a favorite method of raising state road funds. It is also used to a limited extent by cities for raising street maintenance and repair funds. It is not directly used by towns, townships, or counties.

The motor license fee applied to a state system of highways for construction and maintenance may be considered as a *ready-to-serve* charge or *potentiality tax*. Every vehicle is a potential user of the roads and may, therefore, be charged a reasonable amount for their construction and upkeep. Since a ready-to-serve charge may logically be proportionate to the service offered, a motor vehicle tax may vary with size, weight, power, etc., of the vehicle.

Automobile Fees.—At first automobile license fees were levied at a flat rate, ranging from $2 to $5 per annum. It became evident that the larger and more powerful the car the greater the damage to the road or, in other words, the greater the service rendered by the road, and hence a variable scale of fees developed.

The earliest of these schemes was that based on horsepower, either at so much per horsepower or fixed fees for horsepower zones. To this some states added weight, cost, value, or other factors. None of these, however, could cover the amount of service or mileage factor. The establishment of a gasoline tax by every state has taken care of the mileage factor and therefore the motor fee should be only the ready-to-serve charge. Some localities seem to favor a flat rate for all vehicles but, in general, a variable fee is favored. For this purpose the horsepower method seems as satisfactory as any and has the advantage of being simple to apply and easy to understand, provided a reasonably accurate method of figuring the horsepower is established.

Horsepower Formula.—The formula generally used for computing the horsepower of gasoline automobile motors for the purpose of levying fees is known as the S.A.E.[1] or N.A.C.C.[2] formula

$$\text{Horsepower} = 0.4\,ND^2 \qquad (19\text{-}1)$$

in which N is the number of cylinders and D is the diameter of their bore in inches.

This formula is approximately correct for motors having equal bore and stroke and when running at a piston speed of about 1,000 ft. per minute. It gives results much too low for the modern high-speed, long-stroke motors. Nevertheless, it will probably continue to be the accepted formula because it is well known, and satisfactory rates based on its use have been established.

Truck Fees.—Trucks are generally charged higher fees than automobiles since they are more destructive to the road, or receive more service from it. Truck fees in general are based on weight rather than horsepower. With the universal adoption of pneumatic tires for trucks it would seem that the horsepower should be taken into consideration, since the lighter, higher powered, faster truck might demand as much from the road as the larger, heavier, but relatively lower powered and slower truck. Some combination of horsepower and weight would probably be more equitable than either horsepower or weight alone.

Commercial Vehicles.—The problem of fees seems to have been viewed originally from the standpoint that all vehicles were privately owned and used on private business. The growth of the paved road systems and the development of the truck and bus have brought forth the commercial vehicle which furnishes transportation for hire. It seems to be an accepted principle that public property should not be exploited for private gain without compensation. Thus bus companies or trucking concerns using the highways may reasonably be expected to pay an extra fee since the highway becomes the equivalent of a capital investment to them. This idea has led to high license fees and also to mileage charges. They seem to have been levied wholly at random and therefore are far from uniform and probably are

[1] Society of Automotive Engineers.

[2] National Automobile Chamber of Commerce.

also far from equitable. A sound basis for the taxation of commercial carriers has not, as yet, been devised.

Wheel Tax.—A wheel tax is a license fee levied by a city and is legal in several states. It normally and properly is limited for expenditure on street work only. Since a vehicle owned in a city must of necessity use a city street, this tax is more of a service charge than a ready-to-serve charge. It is usually levied similarly to the state license. It is one of the most just taxes imposed on the automobile owner since it renders him a direct, tangible service in the form of better streets and at the same time makes every motor-vehicle owner contribute to this work irrespective of whether he owns other taxable property or not.

Fuel Taxes.[1]—A motor fuel tax popularly known as a *gas tax* is the most recent device for equalizing the service charge for roads and for raising funds for road work. Investigations have shown that the fuel consumption is a general index of total operating costs and that it varies with the weight, speed, distance, character of road surface, and the type of vehicle. Thus the fuel consumption indicates the relative service rendered, and a gas tax is an equitable method of levying a *service charge.*

The early fault in the application of the gas tax was the tendency for the state to levy the tax and reserve all of it for rural highways. If a service tax is to be levied its proceeds should go to finance the projects rendering the service. Many vehicles do little or no traveling on state highways. It is, therefore, extremely difficult, if not impossible, to justify a gas tax to such owners on the grounds of service rendered, if the proceeds are to be used solely on state roads.

Rural highways and city pavements are separately administered but jointly serve traffic. A service tax, therefore, should be jointly used. A properly levied gas tax should be divided between the rural and municipal authorities. It is sometimes justifiable or expedient, however, temporarily to divert the entire proceeds of the gas tax to any one of the agencies in order to complete in the shortest possible time some established program of highway improvement. Thus if the state has established a definite system of trunk roads it is reasonable to use the entire gas tax funds for a term of years to complete the system, for in this way the maximum service will be rendered to the people of

[1] Introduced by the State of Oregon in 1919.

the state. Or it may be entirely logical to divert the entire gas tax to completing trunk highways inside the cities only.

It is often proposed to distribute gas tax funds, and even motor fees to the local authorities. This is proper *after* a primary system has been provided. It should always be done in some form of state aid, so that the state retains a large degree of jurisdiction over the expenditure of the funds. It is fundamentally unsound to make the state simply a collecting agency for funds to be spent by local bodies as they see fit.

Since 1928 there has been a steady trend toward greater expenditure of gas tax funds in the municipalities under state authority or supervision. Unfortunately, however, under the stress of economic conditions there has been a strong tendency to divert gas tax monies to other purposes than highways and large sums have been so diverted. This is fundamentally wrong since a service tax should be used only to supply the service for which it is collected.

Special Assessments.—A special assessment is a direct tax levied against property for a specific purpose and is based on benefits conferred. Special assessments are used only to a limited extent for rural highway financing. On the other hand, they form the principal method of raising funds for street improvements. A street improvement is looked upon as a local improvement conferring evident benefits upon adjacent property. The property may therefore be taxed to pay the cost of the improvement.

Gifts.—Gifts are not taxes. They are donations of land, money, materials, etc., for the purpose of promoting the work. They may result in reduced taxes and hence are related to the problem. As a whole, gifts form only an exceedingly small part of highway revenue.

Toll.—Toll is a specific charge made against the user for the use of a definite section of road or of a bridge. Toll roads developed in the early days of road building. Private enterprises were induced to improve and maintain the roads and were permitted to charge toll to cover the cost. The general policy in America is adverse to toll roads but a few such roads still exist. The latest notable example is the toll automobile road to the summit of Pikes Peak in Colorado.

Except for the interference with traffic movement, *toll bridges* are not objectionable and sometimes form the only solution of the

finance problem, since the local taxing ability may not be sufficient to raise the necessary funds. Toll bridges and ferries are therefore not uncommon.

BOND ISSUES

A bond issue is a method of borrowing money. It is not a method of financing except in the sense that it provides funds for immediate use to be paid out of future income.

A *bond* is the promissory note of a firm or corporation. It is a written agreement that, for value received, a certain sum of money will be paid at a certain time, in a certain manner, with interest at a certain rate. The type of a bond is fixed by its terms of payment, the nature of the issuing organization, and the security.

The integrity of a bond is protected by its *security*. Commercial concerns usually secure their bonds by mortgages on tangible property. Public bonds are secured by the taxing ability of the political unit issuing the bonds. This in reality makes the taxable property the security. Since several political units overlap in their taxing powers, a limit to the amounts of bonds each may issue, known as the *bond limit*, is usually fixed by law or by the state constitution.

Sinking Fund Bond.—This type of bond requires two separate and distinct transactions by the issuer. The first is the bond itself. The second is the accumulation of funds to retire the bond at maturity.

The bond itself is merely a simple agreement that a sum P shall be paid at the end of N years with interest at the rate r payable at stated intervals, usually annually or semiannually. No payments are made on the principal during the term of the bond; hence the annual interest Pr is constant throughout the term. The direct cost of such a bond, therefore, is

$$C = P + PrN \tag{19-2}$$

The sinking fund is the accumulation of funds during the term of the bond sufficient to retire it at maturity. Since the income of the issuer is received periodically, deposits in the sinking fund are made at such periods. It is evident that equal annual deposits of P/N would provide P in N years and thus retire the bond. The total cost, however, would be as given by Eq. 19-2. It is possible to reduce this cost by investing the deposits to the

sinking fund in such a way that they will earn interest while accumulating. It is usually assumed that equal annual deposits to the sinking fund are placed at compound interest during the term of the bond. The amount of each deposit A is the annuity at the rate r' which will yield P in N years, or

$$A = \frac{Pr'}{(1 + r')^N - 1} \tag{19-3}$$

If the sinking fund is not invested, $A = P/N$ as previously indicated.

The annual tax T is equal to the annual interest plus the annual deposit to the sinking fund, or

$$T = Pr + A \tag{19-4}$$

and the total cost becomes

$$C = NT = N(Pr + A) \tag{19-5}$$

Example.—Assuming a sinking fund bond issue of $10,000 at 4 percent for 10 years, the sinking fund to be invested at 3 percent.

Annual interest Pr	$= 10{,}000 \times 0.04$	= $	400.00
Annual deposit A	$= \dfrac{10{,}000 \times 0.03}{(1 + 0.03)^{10} - 1}$	=	872.30
Annual tax T	$= Pr + A$	=	1,272.30
Net cost C	$= N(Pr + A)$	=	12,723.00
If the sinking fund is not invested the			
Gross cost	$= 10{,}000 + 10{,}000 \times 0.04 \times 10$	=	14,000.00
Saving by investing sinking fund		=	1,277.00

Unless the sinking fund is well invested, the sinking fund bond is the most expensive type. It is a favorite with commercial concerns where careful administration and the opportunities for good investment make for high returns on the sinking fund. These bonds are also favored by certain investors, since the entire sum remains invested until maturity.

Sinking fund bonds are not desirable for public bodies. A desire to reduce taxes may prevent the formation of an adequate sinking fund or the sinking fund may be diverted to other purposes, thus requiring refunding at maturity. Again, the investment of the sinking fund may not be advantageous and will result in high cost of the issue. Note that this is simply mismanagement and not graft.

Annuity Bonds.—This type of bond requires but a single transaction, since it is so arranged that the sum of the annual

interest on the unpaid part of the principal and a payment on the principal form an annuity of constant amount. The annual tax T is equal to this annuity and the total cost of the bond is NT. It can be shown that

$$T = \frac{Pr}{1 - (1 + r)^{-N}} \tag{19-6}$$

This type of bond is little used in highway work.

Example.—Assume an annuity bond issue of \$10,000 at 4 percent for 10 years.

$$\text{Annual tax } T = \frac{10{,}000 \times 0.04}{1 - (1 + 0.04)^{-10}} = \$\ 1{,}232.91$$

$$\text{Total cost} = 10 \times 1232.91 = \$12{,}329.10$$

Serial Bonds.—This type of bond also requires but one transaction, since it provides for the payment of the principal in installments with interest on the unpaid balance. The installments are usually equal and generally payable annually. Each bond may provide for installments, but it is more common to issue a series of bonds each having a different term so as to make up the installments. Thus \$10,000 payable in 10 installments would be made in a series of 10 bonds (or groups of bonds) of \$1,000 each, with maturities ranging from 1 to 10 years. Each year the bond or bonds maturing that year would be retired.

The annual installment on the principal p is

$$p = \frac{P}{N} \tag{19-7}$$

The unpaid balance with n installments paid is

$$B = P - np \tag{19-8}$$

The annual interest with n installments paid is

$$i_n = Br = r(P - np) \tag{19-9}$$

The annual tax with n installments paid is

$$T = p + i_n \tag{19-10}$$

The annual interests form a descending arithmetic series in which the first term is Pr, the common difference is $\frac{Pr}{N}$, and the

last term is $\frac{Pr}{N}$. Summing this series the total interest I is

$$I = \frac{N}{2}\left(Pr + \frac{Pr}{N}\right) = Pr\frac{(N + 1)}{2} \tag{19-11}$$

The total cost is

$$C = P + I \tag{19-12}$$

Example.—Assuming a serial bond issue of \$10,000 at 4 percent for 10 years.

The annual tax the first year $= \frac{10{,}000}{10} + 10{,}000 \times 0.04 = \$1{,}400.$

The annual tax the last year $= \frac{10{,}000}{10} + 1{,}000 \times 0.04 = \$1{,}040.$

The total interest $= 10{,}000 \times 0.04 \times \frac{11}{2} = \$2{,}200.$

Total cost $= 10{,}000 + 2{,}200 = \$12{,}200.$

Compare these values with the example of sinking fund and annuity bonds previously given.

Serial bonds are the most satisfactory for public use, since a tax must be levied each year to cover the proportional part of the principal and the accrued interest, which form a debt due, so that the transaction to date is closed each year. Although somewhat less advantageous than the sinking fund bond to investors, they find ready sale.

Sale of Bonds.—Bonds are negotiable instruments and therefore may be bought and sold. The price fluctuates with the value of money, the type of bond, the interest rate, and the security, all of which affect the earning power of the bond to the investor. If the bond is bought at *par* or face value it earns its nominal or face rate of interest. If bought below par or at a *discount* the earning rate is increased. If bought at a *premium* the earning rate is decreased. Since interest becomes due on fixed dates, while the bond may be sold at any time, all bond sales are made subject to the *accrued interest*. Thus the sum actually paid for a bond is its market price plus the amount of interest it has earned since the last interest date.

Bonds are sometimes sold by the issuers on the open market but more commonly in road work bids are asked for and the bonds sold to the highest bidder. Contractors are often required to accept local improvement bonds at par in payment for their work. The contractor markets the bonds, and he must adjust his bid to the market value of the particular bonds.

Bond Elections.—Nearly every proposal to issue bonds for roads must be subjected to a referendum election. Before the people can vote intelligently, and before many will vote at all, they must be fully informed concerning the proposition. The location of the roads to be improved, the nature of the improvements, the estimated costs, and the tax rates should be accurately and fully circulated. With annuity and sinking fund bonds the annual tax is constant and hence can be given in a single sentence. With serial bonds, which are most generally used, a *bond table* should be prepared. This table should give, for each year of the life of the bonds, the total principal outstanding, the payment due on the principal, the amount of interest due, the total of principal and interest due, the tax rate required and other pertinent information. Proper and adequate publicity is essential to a successful bond-issue campaign.

Guarantee Bonds.—A guarantee bond differs from the foregoing in not being an instrument for borrowing money but a financial guarantee for the faithful performance of work or for loss by damage, etc. Thus a contractor is required to give a guarantee bond for the faithful performance of the work, for protection against damage, or to guarantee maintenance for a term of years.

Guarantee bonds may be furnished by individuals possessing satisfactory financial assets or by companies organized for such business. The former are known as *personal bonds,* the latter as *surety bonds.* In case of default the bonding company or individual makes good the agreement to the extent of the bond.

FINANCING RURAL HIGHWAYS

Rural highway financing, throughout the entire range, consists of a system of taxation more or less based on a proposed scheme of improvement or on ordinary needs for road upkeep. The funds being thus provided, the plans, details, etc., are worked out and the work done. Note the contrast with municipal financing following.

Township or Local Roads.—The local unit finances its road work almost entirely by direct property tax and poll tax. General taxes up to some fixed limit provide income for normal maintenance and repair and some improvement. Extensive improvements are usually provided for by the ability to increase

the tax by vote of the people for the specific purpose. Bonds may or may not be issued.

The road work is in charge of the local road authorities who proceed to carry out the work provided for by the taxes. In some states special assessments may be used for part of the cost and special proceedings are required to levy the same. County aid or sometimes state aid is often available to the township. In such cases it is more common and always better for the higher power to supervise the expenditure of the joint funds. In some cases the county is the smallest unit having jurisdiction over roads.

County Roads.—Where local roads are under township control, the county may have jurisdiction over a secondary group of roads intermediate between the local roads and the trunk lines or may include the latter.

County funds are principally derived from general taxes. Again a maximum tax rate is fixed and for more extensive work an election to increase the tax is necessary. County road bond issues are quite common. When the entire project is financed by the county, or by county aid to a township, the county officials proceed with the work in accordance with the general plan and available funds.

State aid is assistance given to the county by the state for road building. The amount of state aid varies between the different states and the schemes of administration are just as variable. In some cases the entire initiative and administration lie with the county, in others the initiative lies with the county but construction lies with the state. In general, state aid gives excellent results for promoting the improvement of the secondary or county system of roads. It has often been tried as the scheme for building a connected system of state trunk highways but has never been successful. Such work can be done to best advantage only by the state. Gas tax funds may be used for state aid.

State Roads.—The states finance their road work principally by motor license fees and gasoline taxes. Some states do comparatively little state work, confining their activities to aiding the counties, etc. Other states have strongly centralized highway departments which devote primary attention to a state system of trunk highways. Others follow an intermediate plan. The money received from fees or taxes is appropriated to the proper

bodies, state or county, which then proceed to construct and maintain the roads within the limits of the available funds.

Federal Aid.—Aid is given the states by the federal government. The original Federal Aid Law was passed in 1916 and the general scheme then devised is still followed with a few modifications. Successive Congresses have appropriated additional money. After a small amount is deducted for the supervision of the work, one-third of the remaining funds is allotted to the state according to population, one-third according to area, and one-third according to post road mileage. The Department of Agriculture, operating through the Bureau of Public Roads, administers the federal aid.

Under the Federal Aid Law each state must have a state highway department and must supervise the federal aid work. The Department of Agriculture allots the funds to the states, after which the initiative is with the state. The state makes the surveys, plans, etc., and submits them to the Bureau of Public Roads for approval. A project agreement is then entered into. After the road is built and inspected by the Bureau of Public Roads, one-half of the cost but not more than $20,000 per mile is refunded to the state.

In 1933 and 1934 the United States Government, in addition to the customary federal aid, appropriated large sums for additional road and street work as an emergency relief measure. These funds were allotted and administered separately and in a different manner from regular federal aid on account of the imperative and temporary conditions existing. Whether future appropriations will be made depends on the general economic condition of the country and cannot be foretold.

National Roads.—The national government does not build roads except in purely government property, military reservations, national parks, and national forests. Contrary to the experience with state-and-county work the scheme of federal aid seems to meet the present needs of national participation in road building.

CITY PAVEMENT FINANCING

General Taxes.—A city may expend general funds for street purposes. In addition, a wheel tax may be levied in some states for the care and improvement of streets. Few municipalities, however, have sufficient funds from such taxes to provide

adequately for maintenance, repairs, and minor improvements; consequently other measures of financing street improvements must be found. Gas tax funds are now generally available.

Local Improvements.—A local improvement is one which, by virtue of its nature and location, confers specific benefits on adjacent property. Thus a pavement project, although it might include every street in a city, becomes a local improvement.

Since a local improvement confers local benefits, local taxes may be levied to pay for the improvement in proportion to the benefits conferred. This form of a tax is known as a *special assessment*. In some states it is known as a *special tax*, particularly when only abutting property is taxed.

It is an established principle that an assessment cannot be more than the benefit. The difficulty is to determine the benefit. Some states attempt to do this by limiting an assessment to a fixed percentage (25 to 100) of the value of the property. This is fundamentally wrong. It penalizes the improved property for the benefit of the unimproved and overlooks the fact that the improvement may be the one thing required to increase the property value. It has been repeatedly demonstrated that properties for which there was practically no market, even at a very low price, have immediately been sold at increased prices with the purchaser assuming the assessment when an improvement costing more than the nominal sale price has been put in.

The increased fair cash market value has been cited as the measure of the benefits. In applying this, however, the total consideration including both the direct money concerned and the assessments assumed must be taken into account.

Levying an Assessment.—Levying an assessment may be interpreted as either an executive act or a judicial act. In some states the former is done, while in other states the latter.

As an executive act, the levying of the assessment is done by the municipal authorities in a definite manner fixed by law. The right of appeal to the courts on grounds of illegal procedure or inequitable or unjust assessment is always provided. This method is simple, direct, requires short time, apparently is no more unjust than any other, and saves money, because there are no court costs except on appeal.

In the legal procedure, the assessment is made by a court of record. The municipality proceeds to a certain stage and then must petition the court to levy the assessment. Court action

then must take place until the assessment is confirmed, after which the jurisdiction returns to the city for the letting of the contract, etc. This method is clumsy and costly. It cannot be shown to be more just and fair than the other or to protect the individual more adequately. Court delay and legal technicalities absorb valuable time and the unnecessary legal expenses add to the total cost.

Amount of the Assessment.—In some instances the actual assessment is levied after the work is done and the exact costs are known. This method has the advantages that the assessment agrees with the actual cost, the time of payment does not begin until the job is done, there are no excess costs to finance in unfavorable cases, and no excess assessments to refund if favorable bids are obtained.

In other cases the assessment is spread on the estimated cost. This has the advantage that collections may begin before the work is finished. It has the disadvantages that, if the estimate is low or contingencies arise, more money is needed and a supplementary assessment is necessary, while if the estimate is high the excess funds must be refunded. Some laws are so worded or interpreted as to prevent the inclusion of certain items of cost, such as contingencies, engineering services, and interest deficiencies. This has led to the practice of *loading the estimates.* This consists of increasing the estimated quantities sufficiently to provide the necessary funds which usually amount to 2 to 6 percent.

Spreading the Assessment.[1]—The spreading of the assessment over the various pieces of property requires good judgment and scientific methods. Most laws provide a commissioner to do this work and often the commissioner's qualifications are purely political. The spreading of an assessment should always be done by the engineering department.

The method of assessment should be as equitable as possible, simple in application, definite in character, and as free as possible from arbitrary factors. If an objecting property owner can be shown that his neighbor's assessment was figured in exactly the same way as his own, he is going to be easier to pacify, even if the method is not perfect, than he is if the assessment is largely arbitrary.

[1] Distribution of Costs of Assessable Improvements, *Civil Eng.*, Vol. 3, No. 4, p. 222, April, 1933.

Various factors affect the spreading of assessment, such as the street plan, the type of improvement, the size and shape of lots. Various systems of spreading have been used. The more important ones follow.

Frontage Method.—This method provides that the assessment on any lot bears the same ratio to the total assessment as the frontage of the lot bears to the total frontage. The frontage is measured at the property line of the street. The total assessment is divided by the total frontage which is the *rate per front foot.* The assessment on any lot is found by multiplying its frontage by the rate per front foot.

Where the lots all front on the improvement and are approximately the same depth, this plan is satisfactory for practically all kinds of improvements, and all other methods reduce essentially to this one under these conditions. The frontage rule does not, however, permit assessing of lots not directly fronting on the improvement, does not provide for variation in depth, and often works a hardship on corner lots. When the improvement is on a cross street the corner lots are affected on the long side, and the assessment becomes heavy, while interior lots are exempt. For example, if in Fig. 19-1 the rate per front foot is \$6.11 the assessment on lot 1 is \$427.70, on lots 2 and 5 it is \$366.60, and on lots 3 and 4 it is \$305.50, while lot 6 is exempt.

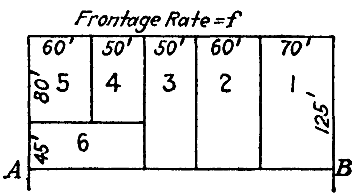


FIG. 19-1.—Assessment plat.

Area Method.—With this method each lot is assessed in proportion to its area. The area method is the correct one for drainage purposes and is sometimes used on lighting systems but is rarely applied to pavements. Assessments may be made on lots not contiguous to the improvement but the amount to each must be determined either arbitrarily or in some other way, which gives rise to the following method.

Area-distance Method.—This scheme is based on the theorem that each unit of area similarly located with respect to the improvement should be assessed at the same rate. The assessment is made directly proportional to the area and inversely proportional to the distance from the improvement.

An axis is chosen at a convenient location, usually the middle of the block. The assessment on a lot is made in the proportion

that the product of its area and the distance of its center from the axis bears to the product of the entire area and the distance of its center from the axis. Since these products are the moments of the areas about the axis, this method is often known as the *moment-area method.*

If the lots are shallow on one side of the street and deep on the other, two or more axes may be employed on the deep side. This imitates the zone method in part and the curve method in part. When a rectangular system of uniform size of lots is laid out six to the block, the assessments of the three lots adjacent to a cross street bear the relation of 1:3:5, giving the so-called 1-3-5 method. For eight lots the relation is 1:3:5:7, for 10 lots, 1:3:5:7:9, etc.

This method is particularly adapted to a rectangular block and lot systems but may be adapted to irregular layouts by using curved or broken lines for axes. It gives a decreasing assessment on lots away from the improvement but is criticized in that the decrease is not rapid enough near the improvement. Since the decrease is directly proportional to the distance from the improvement, the interior lots assume, proportionately, too high a share. It is a useful and sufficiently equitable method for determining the relative assessments when the back ends of corner lots have been sold off.

In Fig. 19-1 the assessments on lots 1, 2, and 3 would be the same as under the frontage method. With the axis at AB and a front-foot rate of \$6.11, the assessment on lot 4 would be

$$\frac{50 \times 6.11 \times 50 \times 80 \times 85}{50 \times 125 \times 62.5} = \$265.91$$

Similarly the assessment on lot 6 which formerly was exempt is

$$\frac{110 \times 6.11 \times 110 \times 45 \times 22.5}{110 \times 125 \times 62.5} = \$87.10$$

Zone-area Method.—In this method zones of uniform depth parallel to the street lines are laid out and to each zone a rate of assessment arbitrarily assigned. Each parcel of land then is assessed in accordance with the area contained in each zone. Under certain conditions this method may become identical with the area-distance method or with the following one. This method possesses no advantages over the preceding one and generally is much more cumbersome to use. With irregular

street plans the zones are established arbitrarily to meet the conditions as nearly as possible.

Benefit-factor Method.—This is the general method of spreading the assessment. It is based on the theorem that the assessment shall decrease as the distance from the improvement increases. The rate of decrease may have any value.

In practice a curve of benefit factors is determined. It may be an arbitrary graphical curve or a mathematical curve of known equation. The benefit factor for any lot is then found by

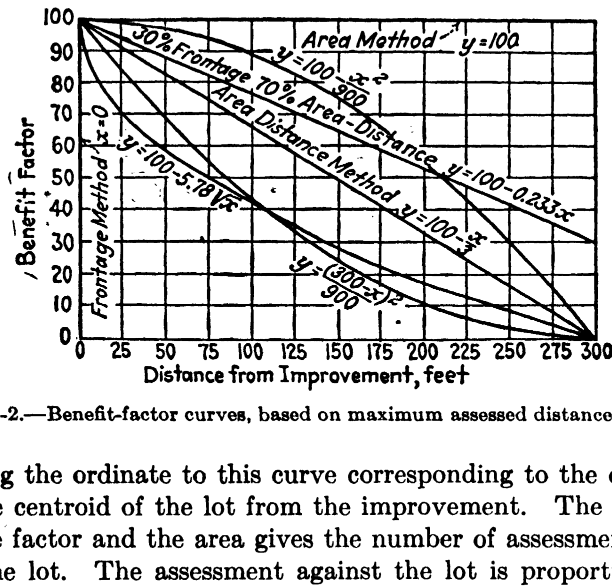


FIG. 19-2.—Benefit-factor curves, based on maximum assessed distance of 300 ft.

finding the ordinate to this curve corresponding to the distance of the centroid of the lot from the improvement. The product of the factor and the area gives the number of assessment units for the lot. The assessment against the lot is proportional to the ratio of the number of its assessment units to the total number of such units in the project.

If the benefit factor is constant this method is identical with the area method. If the distance item is omitted it becomes the frontage method. If the benefit factor decreases directly with the distance, then the area-distance or moment method results.

Figure 19-2 shows several benefit factor curves based on spreading the assessment back 300 ft. An infinite number of curves are available. A separate curve must be provided for each change of distance over which the assessment is to be spread.

Service Method.—Sometimes assessments are spread on the basis of service rendered. This is the typical method for sanitary sewer assessments, since the benefits are not in proportion to

the size or length of lot but on the fact of providing a sewage disposal system. It is not adapted to pavement assessments.

Installments.—Assessments are usually payable in annual installments with interest on deferred installments. The usual interest rates are 5 to 7 percent. Pavement assessments rarely run more than 10 years. Sometimes the installments are equal, while sometimes those after the first are made to total some multiples of 100 so as to provide even denominations of bonds. Usually the first is increased and the others reduced.

Bonds.—Bonds are usually issued to cover the deferred payments. They are simple serial bonds and bear the same rate of interest as the deferred installments. They are not general municipal bonds secured by general taxes but are known as *local improvement bonds* and become liens on the property to the amount of the assessment. The assessments are usually collected by the city but if not paid when due are collectible the same as other delinquent taxes.

Contractors are often required to accept local improvement bonds at par in payment for the work.

Interest Deficiency.—Interests on bonds must be paid on definite dates. Also, if a bond is called for retirement before maturity, certain legal notice must be given before interest on it can be stopped. At the same time the property owner has the right to make payment at any time and thus stop the interest. The amount of interest actually collected on the assessment may, therefore, be less than that paid the bondholder. This *interest deficiency* is variable but often amounts to between 2 and 4 percent.

The assessment itself should be sufficient to cover interest deficiency. In some states an item for this purpose may be carried in the estimate. In other states this cannot be done; hence recourse is made to loading the estimates as previously mentioned.

Comparative Costs.—It is sometimes claimed that the total cost of municipal work is unduly higher than similar rural work. This is not altogether true. Undoubtedly, there is some difference, since the latter is financed in a blanket manner, while the former is financed in detail for each job and also often requires more legal procedure.

On the other hand, the complete cost of financing is rarely charged to the rural road. To make the two comparable the

cost of special elections for bonds or taxes, the cost of selling the bonds, the cost of collecting the taxes, interest deficiency, condemnation suits, etc., would have to be added to the engineering cost of the rural road, since these are automatically included in street procedure.

Contrast of Methods.—The following taken from Illinois procedure illustrates the difference in financing rural and municipal highway projects.

State Highways.

1. Appropriation to Highway Department by act of legislature.
2. Surveys, plans, estimates.
3. Receive bids.
4. Let contract.
5. Construction.
6. Sale of bonds as necessary.
7. Collection of motor fees, or other taxes.
8. Make payments to contractor in cash.
9. Pay bonds as they fall due from funds appropriated.

Municipal Highways.

1. Resolution to start, by Board of Local Improvements (B.L.I.).
2. Surveys, tentative plans, engineers' estimate.
3. Public hearing, by B.L.I.
4. Preparation of ordinance including final plans and specifications.
5. Passage of ordinance, by council.
6. Petition to court for special assessment.
7. Report of commissioner appointed to spread the assessment.
8. Court hearing.
9. Confirmation of assessment roll by court.
10. Receive bids, by B.L.I.
11. Let contract, by B.L.I.
12. Construction.
13. Report of completion to court.
14. Final approval by court.
15. Final payment to contractor in local improvement bonds.
16. Collect special assessment and redeem bonds as they fall due.

Right-of way.—The right-of-way is the area included between the property lines. In most cases the right-of-way is an easement for road purposes only. Sometimes actual title in the land is held. Rural highway may be opened, vacated, or modified by proper political units in manner fixed by law. The right-of-way may be donated by the owner, purchased from him, or recourse may be had to condemnation. Usually the local

authorities such as the county or township secure the necessary right-of-way, even for state roads.

Streets usually originate by being donated by the land owners platting lands for additions to the municipalities. They may be extended by the city by purchase or condemnation. In every case the city should have power—*and use it*—to supervise the platting of all additions so as properly to coordinate the plan and obtain proper widths and continuity of the streets. Wise, indeed, is the city that insists on wide right-of-way and systematic street plans.

When right-of-way cannot be acquired by gift or purchase, the right of eminent domain, vested in the public, is called into service, and the land *condemned.* This is simply an enforced sale, the court fixing the price. The price is presumed to be the fair cash market value considering the use of the entire tract, plus the damages resulting by detaching the land under controversy. The usual procedure is to make an offer for the purchase. If it is refused, condemnation proceedings are instituted. A survey is made and the case filed in court. Regular court procedure is then held, usually with a jury, the condemning party being plaintiff and the owner the defendant. After the usual procedure of taking evidence, etc., the jury returns a verdict and the court enters an order. Appeals may be taken. Work cannot proceed until the judgment is given.

When right-of-way must be acquired, its cost, whether purchased or condemned, must be included in the cost of the project and hence be provided for in the financial scheme.

Disturbed Finances.—The recent economic condition commonly called *the depression* brought forth many attempts, both good and bad, to reduce or readjust taxes. Prominent among these efforts was the wholesale diversion of gas tax funds from road work to other purposes. At the same time there was an attitude of general tax reduction. Naturally the normal road program suffered severely in consequence.

These difficulties were apparently compensated to some degree by the enormous grants for federal money during 1933–1935 for road work to create and stimulate employment. So great, however, was the emphasis placed on labor to the exclusion of other essential factors that a great deal of the work was below standard. Improper selection of types, hasty design, insufficient materials, inadequate supervision, and incompetent labor often

combined to the detriment of the results. It must not be thought, however, that all work was poor. A great deal, probably the majority, was excellently done and one can but marvel at the results obtained under adverse conditions. This high-grade work coupled with the relief of needy citizens compensates for, but does not justify, the wastefulness of the poor work.

These conditions must be interpreted as abnormal disturbances. As the country once more enjoys comparative prosperity, the demands for roads will be renewed. Financial difficulties will be stabilized and the troubles of the past will be lost in the prospects for the future.

Problems

19-1. With a rate of 40 cts. per S.A.E. horsepower, what is the license fee for a 6-cylinder car with a bore of $3\frac{1}{2}$ in.? For an 8-cylinder car with a bore of $2\frac{7}{8}$ in.?

19-2. A township with an assessed value of $2,000,000 plans to issue $50,000 in 10-year $4\frac{1}{2}$ percent serial bonds. Prepare a table showing the unpaid balance, the payment on the principal, the interest, the total tax, the tax rate for each year of the term, and the total cost.

19-3. Substitute annuity bonds for serial bonds in Prob. 19-2 and compute the annual tax and the total cost.

19-4. Substitute sinking fund bonds, the sinking fund to be not invested for serial bonds in Prob. 19-2 and compute the annual tax and the total cost.

19-5. Substitute sinking fund bonds, the sinking fund to be invested at $3\frac{1}{4}$ percent, for serial bonds in Prob. 19-2 and compute the annual tax and the total cost.

19-6. A block of $4\frac{1}{2}$ percent bonds with a face value of $1,000,000 and $5\frac{1}{2}$ months' accured interest sells for $1,032,000. What are the premium or discount and the actual rate of interest received by the investor the first year?

19-7. A rectangular city block contains nine lots. One corner lot has a frontage of 80 ft., the other 70 ft. The next two lots from each end have frontages of 66 ft., the other three lots have frontages of 60 ft. If the total assessment on the block is $5,460, what is the assessment on each lot?

19-8. If the lots in Prob. 19-7 are 132 ft. deep and the 80-ft. corner lot has 32 ft. sold off the rear end, what is the assessment on each piece by the moment-area method?

19-9. The lots in Prob. 19-7 are 132 ft. deep. The cross street along the side of the 80-ft. lot is to be paved at a total cost of $17.56 per lineal foot, half of which goes to each side of the street. Assess the proper amount to the middle of the given block by the area-distance method.

19-10. A total assessment of $57,431 is to be divided into 10 installments, the last 9 of which are to be equal and each equal to some multiple of $100 with any excess placed in the first installment. What is the amount of each installment?

CHAPTER 20

OPERATION

Operation is that part of highway administration which relates to the movement of traffic over the highway. It is frequently termed *traffic control.* Operation, however, is broader and more inclusive than the mere regulation of the movement of vehicles. Operation is properly an engineering function. Since the sole object of the highway is to furnish facilities for traffic, it follows that operation is the basic consideration in financing, designing, constructing, and maintaining a road. Safety, convenience, and service must be built into the road, and the roads so used as to give the maximum benefits to the greatest number.

Accidents.—All highway accidents can be attributed to faults in one or more of the following: (1) the vehicle, (2) the road, (3) the traffic regulations, (4) the driver.

The first three are very loath to admit fault and accept responsibility for accident. The last therefore often assumes a large part of the blame that properly belongs to the others. *Reckless driving* is often made to take the blame for faults actually of the vehicle, road, or traffic rules. If *safety appliance standards* similar to those on railroads were in force on the highway, accidents would be vastly reduced. Certain devices, if not whole vehicles, would be ruled off the road. The road builder would have to eliminate such things as the deep side ditch, the soft shoulder, the unbanked curve, and the narrow bridge. The drivers would be licensed and supervised and, finally, traffic regulations would be simplified and standardized (see Chap. 1 and Table 1-3).

Motor Laws.—Every state is a power unto itself in the matter of road and vehicle laws. Some means of securing greater uniformity, especially as related to the operation of the highways, is greatly needed. This may ultimately develop into some form of federal regulation similar to that on the railroads.

Trouble is further caused by the overlapping and conflicting authority of the township, county, state, cities, etc. No inferior

unit should attempt to regulate a matter already covered by a superior unit. It should have the power and the duty to enforce the major regulation directly. The inferior unit, however, should have the power to make additional regulations, not conflicting with superior authority, to govern its local conditions, and these should be also enforceable by the superior unit. Thus the state motor law should be ex officio a part of all municipal traffic regulations and enforceable directly by the city as a part of its law. Local ordinances should then cover local conditions only and state police should have the authority under them when in the city.

Conditions are further aggravated by the tendency of the courts to usurp the legislative powers and write into the laws, by court action, provisions that are not there and were never intended to be there. Further difficulty is caused by the fact that a great deal of legal talent is expended in finding legal ways of breaking or evading the law. The large mass of people tolerate conditions simply because it takes too much effort to secure improvement.

Speed.—The fundamental advantage of motor traffic lies in its speed. Many people, however, seem obsessed with the idea that traffic should be slowed down. The fact is that the reverse is more nearly correct. Collectively, traffic needs speeding up. This does not necessarily mean greater maximum speeds but it does mean facility for all traffic to maintain a reasonably high speed.

There is no objection to speed per se. Speeds only become objectionable when they interfere with the safe and economic use of the highway by the largest number. Slow speeds may be, and often are, as undesirable as high speeds. Slow vehicles figure in accidents almost as frequently as do the fast ones and are as often to blame. Most speed regulations deal with maximum speeds but the time is near when minimum speeds will also receive attention. Already minimum speeds are in force in several places. Speed limits should be established with due consideration for the needs of traffic and should be high enough to accommodate those needs. They should then be consistently enforced but interpreted with common sense.

Critical Speeds.—Critical speeds may be defined as the normal safe speeds under given conditions. Critical speeds are of

importance on curves, on steep grades, at intersections, and at other places.

The critical speed on a curve may be taken as the speed at which the majority of drivers will travel with ease and comfort. It depends primarily on the radius and the superelevation but is difficult to evaluate. A series of observations on 14 different curves is the basis of the equation[1]

$$S_c^3 = 466R(e + 0.2) \tag{20-1}$$

where S_c is the critical speed in miles per hour, R is the radius in feet, and e is the superelevation in feet per foot of width. This formula is of use in determining the speeds to be indicated by "stated speed signs" and in establishing traffic regulations.

The critical speed at an intersection is such a speed that a vehicle approaching the intersection can clear another on opposing route by slowing or stopping. The conditions are so numerous that general rules cannot be laid down. The National Safety Council is studying this problem.

The critical speed on grades is difficult to estimate. Some consideration of this problem is given in Chap. 15.

Weight.—It is both logical and justifiable to limit vehicular weights, since it permits the making of sound engineering designs for the road and structures. Conflicting interests have kept legislation in regard to weight in a constant turmoil. Most of it, however, has been in regard to gross weights, while wheel loads have become fairly uniform at 8,000 to 12,000 lb. (see Fig. 20-1).

Size.—The size of vehicles and their loads should be limited so that adequate widths of roadway and needed clearances for safety and convenience can be provided. The maximum width is about 8 ft., with 8½ ft. permitted under certain conditions. Occasionally wider loads of special character may be desired but these can be handled by special permit.

The length of vehicle has occasioned considerable trouble. Vehicles of such length as to be a menace to traffic on curves and a nuisance on city streets became so common that limitation became imperative. With few exceptions the limit is placed at 40 to 45 ft. for truck and trailer combination with less for a truck alone. (See Fig. 20-1.)

[1] Critical Speeds on Highway Curves, *Public Safety*, Vol. 8, No. 12, p. 9, December, 1934.

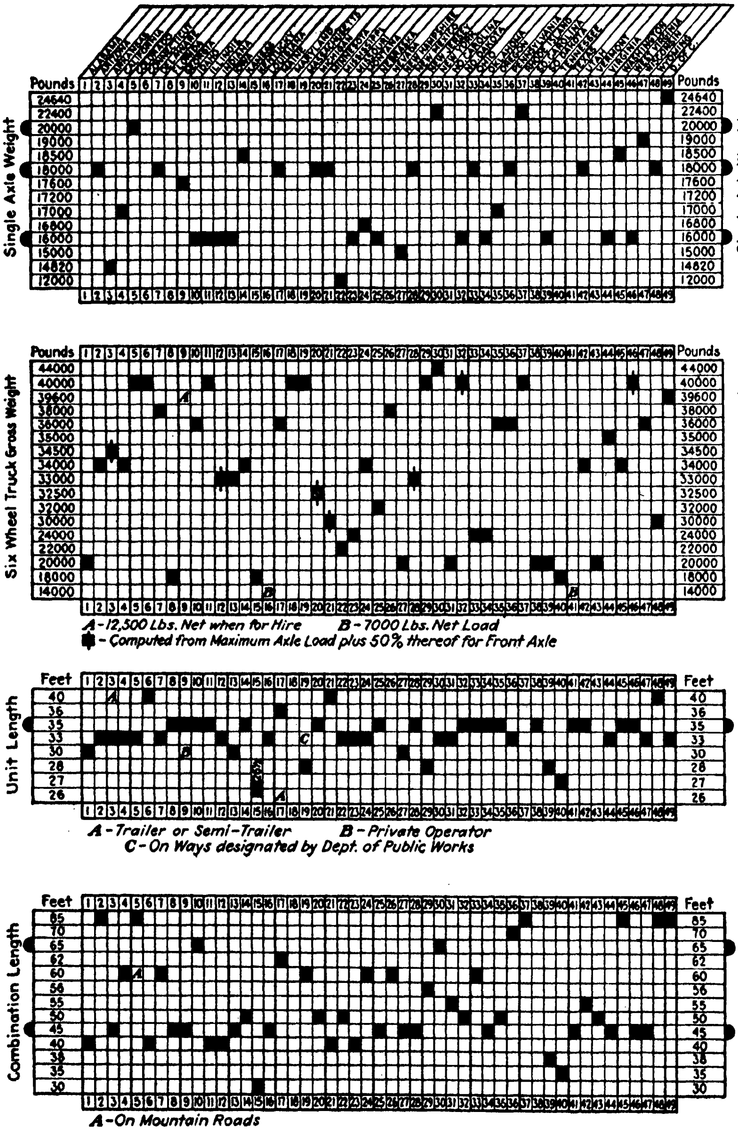


FIG. 20-1.—Legal weights and lengths of motor trucks in 1933. (*General Motors Truck Company.*)

The height more or less regulates itself but several states have added height restrictions generally about 11 to 12 ft.

Lights.—At night every user of the road should carry proper lights for the protection of himself and the safety of others. This should apply indiscriminately to every type of traffic unit whether pedestrian, wagon, or motor vehicle, although the number and kind of lights may be varied. There is no sane reason why the pedestrian should be permitted to roam the road without lights when the same individual in an automobile would be required to display several.

Vehicular lights are primarily signal lights to give warning to others of the presence, size, and movement of the bearer.

Headlights serve both as signals and to illuminate the road. All vehicles more than 3 ft. wide should carry two as signals, one at each side, while narrow vehicles should carry one. When a vehicle is standing, one light on the side next to traffic is sufficient, if the vehicle is turned off the traveled way. Headlights should be white in color and bright enough to illuminate the roadway but without blinding an approaching driver. Most headlights meet these requirements very well when properly adjusted and focused. Many are arranged so that the beam can be depressed or deflected to prevent excessive glare to an oncoming driver.

A *tail light* is a signal light to protect the rear of the vehicle. There is a growing tendency to use two tail lights. This is desirable since it indicates the width of the vehicle and also offers protection if one burns out. Tail lights should always be displayed at night both when the vehicle is running and when standing. The universal color is red but a small white glow is desirable on account of the appreciable number of drivers who are color-blind to red. This is generally furnished by the illumination of the number plate and the effect is increased by keeping the plate clean.

A *stop light* is an auxiliary tail light which shows both by day and by night only when the car is decelerating. It is an excellent device and should be standard equipment on all motor vehicles. The color is generally red and it should be bright enough to show a distinct flash even in bright daylight.

Front and rear *markers* are required in some states on truck and busses. These generally take the form of three green lights in a horizontal row on the front, and three red lights similarly

arranged at the rear. The markers should be standardized and universally adopted.

Some states also require *clearance lights* along the sides of trucks and busses. These should be lights not reflector buttons. They should be placed so as to be visible from both the front and rear for the convenience of passing vehicles from either direction. Sometimes the color is not specified but more frequently red is used for the right side and green for the left; but our road rules make the reverse arrangement desirable.

Trucks and busses are generally required to carry flare torches or fusees for use at night if a stop is made on the highway. Flags are sometimes used by day. The night signals at least should be made a uniform and universal requirement. The extension of the requirement to ordinary automobiles merits careful consideration.

The whole system of lights should be definitely fixed by law. Provision should be made for frequent inspection of the lights and the law strictly enforced. The provisions should be uniform throughout the country, if not internationally.

Brakes.—The brakes are an important part of motor car equipment. They must be designed to suit the vehicle and then maintained in good working condition. The car builder who does not provide adequate brakes and the owner who habitually neglects keeping them in good working condition are both criminally negligent.

Passenger automobiles are equipped with four-wheel brakes and most trucks have brakes on all wheels. Some semi-trailers and trailers depend on the truck unit for braking. This should not be tolerated. So important are adequate brakes that they should be frequently inspected and tested. This calls for proper legislation aided by police supervision.

Traffic Classification.—Traffic is ordinarily classified as *light*, *medium*, and *heavy*. These terms are indefinite in that they are used to indicate both weight and density. Weight of the traffic units is of importance in designing the structure but is much less important than the density of traffic in controlling traffic.

Traffic may be classified according to density, as follows:

Sparse traffic consists of a few vehicles spaced at long intervals. *Open* traffic is such that all vehicles operate freely at normal road speeds without appreciable interference. Some bunching of vehicles into small groups may occur. *Dense* traffic shows con-

siderable interference and bunching to such an extent that speeds are reduced but the vehicles can still make fair progress. *Congested* traffic is such that free movement is lost, reasonable progress is curtailed, and constant attention is required to avoid collision. The last stage of congestion is when the traffic is *stalled.*

Obviously, there are no sharp divisions between these classes and they merge into one another. Changes in operating conditions may change the character of the traffic even though the same number of vehicles are concerned. Thus a steep grade, by reducing the average speed, may change open traffic to dense traffic or an intersection by reducing the traffic capacity may develop congestion in otherwise only moderately dense traffic. The problem, then, of the highway designer is to design a road as free as possible from conditions that tend to increase the traffic density. This phase is all too frequently neglected.

Intersections.—Intersections at grade are always points of potential congestion and danger. Traffic control at an intersection is therefore the most difficult of any point on the road. If crossing traffic only existed it would be much simpler than it is with many vehicles turning off one highway onto the other. On the rural road where intersections are far apart the problem is quite different from that of the streets of even a moderate city where the intersections are so close together that they exert a large influence on each other (see Chap. 16).

Right-hand Turn.—The right-hand turn is the simplest and easiest to handle. In making the turn a vehicle does not cross another line of vehicular traffic. If the radius is long enough for the turn to be made at a fair speed, the impedance to following traffic is small. Vehicular traffic, however, must cross two lines of pedestrian traffic, with the result that there is often much mutual interference.

Left-hand Turn.—This is more troublesome and harder to control because the vehicle not only must pass through the intersection but in so doing must cross the traffic lines of both vehicular and pedestrian traffic on both streets.

In order to relieve congestion the left-hand turn is sometimes prohibited but this should never be done except as a last recourse and only after careful study of the particular corner and the effect on traffic. It cannot be assumed that the left-hand turn is eliminated by prohibiting it. The natural flow of traffic from

origin to destination calls for a certain amount of left-hand movement. The best that the prohibition can do is to change the traffic routes and in so doing invariably increases the number of turns and usually also the distance to be traveled. Frequently the prohibited left-hand turn develops congestion on other streets and at other corners out of all proportion to the saving effected. Figure 20-2 shows diagrammatically some of the effects of attempting to eliminate the left-hand turns on city streets.

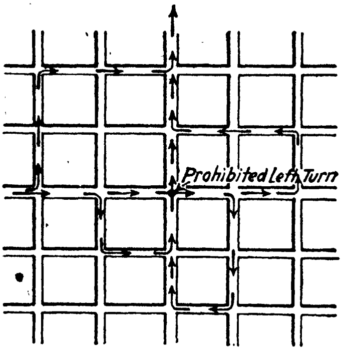


FIG. 20-2.—Effect on traffic of prohibiting a left turn.

The U-turn.—The complete 180-deg. turn or U-turn is always objectionable since it crosses all lines of vehicular traffic. With very open traffic or where intersections are far apart it may be tolerated but it should never be permitted on a busy street. The number of vehicles desiring to make a U-turn is small and the economic loss to them by the prohibition is more than offset by the gain to the remainder of the traffic.

Control of Intersections.—Naturally the control of traffic at intersections has received the most attention. In the larger cities there has been a gradual development from unrestricted movement to more or less complicated systems using many special devices. The smaller towns, in attempting to copy the larger cities and being handicapped by lack of funds, rather paradoxically have become a fruitful field for the sale of traffic devices. Many of the absurdities of traffic regulations found in smaller municipalities are due to sincere and enthusiastic efforts to serve, misdirected by the wiles of a talkative salesman.

Free Intersection.—The free intersection permits traffic to filter through without restriction. Open or close traffic works quite well in this way and the cost of control is a minimum. The intersections should be easily visible and protected by warning signs, if the sight distances are short. They should be free from trees, shrubbery, etc., in all cases, so that there is a maximum sight distance. This is the most common type.

Boulevard Stop.—This system provides for the traffic on the main thoroughfare to run free while the cross or entering traffic

must stop and filter its way in or across. The system is especially useful where one road is densely traveled with the other comparatively sparsely. It is low in cost, demanding only a few signs which, however, should be illuminated on city streets and so set as to be visible with the headlight on rural roads. It is quite effective with a little police supervision and, with a wise choice of arterial streets, will meet the requirements of most locations in the majority of our cities. Its worst defect is an inflexibility or arbitrary restriction during slack hours, but in this respect it is not so bad as the traffic signal.

Traffic Officer.—The traffic officer is the most flexible system of traffic control. He can be shifted from corner to corner as

TABLE 20-1.—LENGTH OF BOULEVARD STOPS
(Green and Wright Streets, Champaign, Ill., 1934)

Number of cars stopping[1]	Percent stopping less than 1 sec.	Percent stopping less than 2 sec.	Average stop, seconds	Maximum stop, seconds
365	44	59	2.9	21
387	44	52	3.9	25
408	36	. .	2.6	20

[1] The traffic on the primary street was approximately three times these figures. Total traffic about 12,000 per day.

changing conditions may require and can be placed on duty during the hours when needed and kept out of the way when not wanted. When on duty he supersedes any device that may be used at other times. Where more or less continuous control is required the officer system is expensive and therefore a mechanical system is substituted.

Traffic Signals.—A traffic signal is a mechanical device for controlling traffic at intersections. The indications are given by colored lights and are regulated by a controller. The colors are usually green for go, amber for change, and red for stop. Some modifications may be made in complicated intersections.

The *time-cycle signal* repeats a red-amber-green-amber-cycle on a definite time schedule which is maintained irrespective of change in the volume and distribution of the traffic. The go time should not be less than 10 sec. or reasonable movement cannot be made. The stop period should not be more than 45 sec. or

traffic becomes restless. The total cycle is usually 1 to 1½ min. but some studies[1] indicate that relatively short cycles are more efficient than long cycles.

In the *traffic-actuated signal* the traffic regulates the cycle by means of electric impulses sent to a control box by vehicles passing over suitable devices placed in the pavement on each street in advance of the intersection. The basic idea is that traffic is permitted to flow on one street until a call for the signal is made by traffic on the other street, but many refinements and modifications are possible. Time limits on the changes result in the signal's behaving the same as a time cycle at continuous peak movement but dividing the cycle according to traffic variations at other times. This type of signal is greatly superior to the time-cycle type in many locations.

Signal Characteristics.—With less than three lanes of traffic in each direction the characteristics of signal control are (1) the signal controls entry into, but not movement through, the intersection. (2) Through traffic is protected from cross traffic. (3) Right turns are impeded by unnecessary stops. (4) Left turns are unprotected since they must cross direct traffic in the opposite direction. In fact, hazards are increased by the signal since both movements are made on go indication. (5) The total number of stops is increased. (6) The length of stops, both average and maximum, is increased. (7) Traffic is formed into waves. (8) Vehicles are grouped close together. (9) Average speeds are reduced without reducing maximum speeds.

When roadways are wide enough to permit turns from separate lanes, impedance to right turns can be reduced. The hazard still remains to left turns unless part of the signal cycle is allotted to them, which lengthens the cycle and reduces the capacity of the intersection.

For these reasons a traffic signal is not always a benefit and often is a hindrance. Studies in many places have indicated that a signal should not be installed if the total traffic for a continuous period of at least 3 hr. each day is less than about 800 vehicles per hour with at least 25 percent on the cross street. Turning traffic may change this somewhat.

Synchronized Signals.—On long streets the signals are synchronized to act together. Under the *platoon* system all signals

[1] The Effect of Control Methods on Traffic Flow. *Public Roads*, Vol. 14, No. 12, p. 233, February, 1934.

show the same indication at the same time. The majority of the vehicles move in groups which start and stop simultaneously. The result is a large number of stops and a low average speed. In the *progressive* system the signals act successively at a fixed rate. Thus a car can proceed at this progressive speed the entire distance without stopping. The result is higher average speed and fewer stops.

When a large area with streets in both directions is to be signalized, the problem becomes quite complicated. In general, a modified progressive system acting in both directions can be worked out.

Flashers.—A flashing signal may be placed at definite points of danger. The color may be red, amber, or white. A flasher may also be used at busy intersections. Generally red is shown in one direction indicating a boulevard stop with cautionary amber on the primary road. These signals may be suspended overhead since they are to be seen at a distance and not at close range.

Delays.—Much attention has been given to the causes, number, and duration of traffic delays. The cost of delays has, however, been grossly overestimated. Practically everyone has fallen into the fallacy that a "car-minute" has an actual and constant value irrespective of how such units are accumulated. Thus 100 car-min. occasioned by the delay of 1 min. to 100 cars is considered the same as 100 car-min. caused by the delay of 100 min. to 1 car. Time is not money nor can it be translated into money unless it is available in usable amounts. This does not occur in the first case but does in the second. Furthermore, practically all so-called delay costs are purely fictitious. The only real costs are the operating costs of the idling engine during the delay, except where the delay is so long as to consume a usable amount of time of a hired driver.

Stops.—Stops add a direct cash item to the costs of automobile operation. Little attention has been given to this fact and but few attempts have been made to evaluate the magnitude of the costs. T. T. Wiley,[1] from a limited number of actual tests on automobiles, arrives at a cost of about 0.25 cts. per stop for passenger automobiles at a speed of 30 m.p.h. For a single car this amounts to about $2.50 per 1,000 miles of travel. For a

[1] Cost of Passenger Automobile Stops, *Civil Eng.*, Vol. 5, No. 5, May, 1935.

TABLE 20-2.[1]—EFFECT OF TIME-CYCLE SIGNAL IN CITY OF MODERATE SIZE
(Champaign-Urbana, Ill. Population 36,000)

At Green and Neil Streets

	Dec. 26, 1930, 3:17 to 4:17 P.M.			Dec. 29, 1930 2:07 to 3:07 P.M.			May 25, 1931, 3:45 to 4:15 P.M.			Average percentage
	Green	Neil	Total	Green	Neil	Total	Green	Neil	Total	
Through	196	239	435	183	184	367	113	127	240	54.7
Necessary stops	175	152	327	146	168	314	39	46	85	45.3
Unnecessary stops	*	*	*	*	*	*	86	51	137	*
Total	371	391	762	329	352	681	238	224	462	100.0
Percentage stopped	47.2	38.9	42.9	44.4	47.7	46.0	52.6	43.3	48.0	45.3

At Green and First Streets

	Dec. 26, 1930, 2:10 to 3:10 P.M.			Dec. 29, 1930, 3:13 to 4:13 P.M.			May 25, 1931, 4:20 to 4:50 P.M.			Average percentage
	Green	First	Total	Green	First	Total	Green	First	Total	
Through	273	79	352	253	75	328	207	69	276	51.0
Necessary stops	205	138	343	214	114	328	37	52	89	49.0
Unnecessary stops	*	*	*	*	*	*	104	53	157	*
Total	478	217	695	467	189	656	348	174	522	100.0
Percentage stopped	42.9	63.5	49.4	45.8	60.2	50.0	40.5	60.3	47.1	49.0

[1] WILEY, T. T., "Economics of Highway Traffic Control," Tables 11 and 12, Univ. of Illinois, 1931. (Thesis for the degree of M. S.)

* Amount of unnecessary stops not determined; all stops counted together.

group of vehicles the sum may be considerable, since it represents the combined actual sums paid for gas, oil, tire wear, brake maintenance, etc.

Example.—The intersection of Green and Wright Streets at the edge of the campus of the University of Illinois carries a daily traffic of over 12,000 of which about 23 percent is stopped on Wright Street by stop signs. Careful estimates predict that a traffic signal would stop at least 48 percent of the total traffic which would add over 3,000 stops per day. This would amount to over $2,700 per year in added operating costs.

FIG. 20-3.—Unnecessary stops caused by a time-cycle signal with no traffic on cross street. A traffic actuated signal would have let these vehicles through.

One-way Streets.—Traffic is sometimes facilitated by limiting the movements on certain streets to one direction. This may apply to arterial streets where two serving the same area are close together, to occasional narrow cross streets, and to areas served only by narrow streets. Care must be taken in using this device that traffic movements are not complicated rather than simplified.

Traffic Interference.—All types of traffic exert mutual interference on each other. The more nearly the type of vehicles and the speeds are alike, the less is the interference. Thus streetcars and automobiles have a high interference factor, and horse-drawn and motor traffic mutually slow each other. This interference is very difficult to evaluate, and so far there appear to be very few tangible data.[1] There is also high interference between pedestrians and vehicles.

[1] Use and Capacity of City Streets, *Trans.* A.S.C.E., No. 99, p. 1012, 1934.

Pedestrians.—It must be recognized that the pedestrian has certain rights which must be respected and also that he has certain limitations as to speed and mobility. In return the pedestrian must also learn that the vehicle has similar rights and limitations.

On a rural highway the pedestrian should walk on the *left* side facing vehicular traffic. This enables him to see approaching cars and avoid them, and his own visibility is higher. At night he should protect himself by carrying a light, just as he would if he were in a car.

On the city streets the pedestrian should keep a close eye on the traffic at every crossing. It is a curious fact that the large majority of pedestrians on starting across the street look the wrong way. Traffic approaches from the left on the near side and from the right on the far side and should be looked for accordingly. Traffic signals may or may not control pedestrian movement. With large volumes of both vehicular and pedestrian traffic the pedestrians tend to move with the signal. With smaller volumes they move independently. Despite this natural tendency some cities insist that the pedestrians shall move with the signal. This may be reasonable at some hours and some crossings but at other hours or crossings may be little short of absurd.

Traffic Lines.—On rural highways the width of pavement is kept as narrow as traffic will permit on account of cost. The result is that traffic runs in definite lanes, instead of spreading over the surface. This has a marked effect on the design of slab as well as on traffic regulation. With left-hand drive it is very difficult to keep a vehicle in its proper lane without some form of mark, easily visible to the driver, to show the limits of its rights. This has led to the marking of a center traffic line. It has been the universal experience that such a traffic line adds vastly to the convenience and safety of operation.

On dark pavements the color of the line is usually white. On light-colored pavements black is used. Sometimes yellow is tried but usually the black or white is better. The protecting of the center joint of a concrete pavement with a band of asphalt makes a convenient method of marking a traffic line. This protection is made with asphalt or tar and by widening and smoothing the covering an excellent black line is formed. Several mechanical devices have been developed which make it possible

to mark several miles a day at a very low cost compared with hand painting.

On city streets, traffic lines are used to mark safety zones, parking spaces, and occasionally running lanes at certain locations.

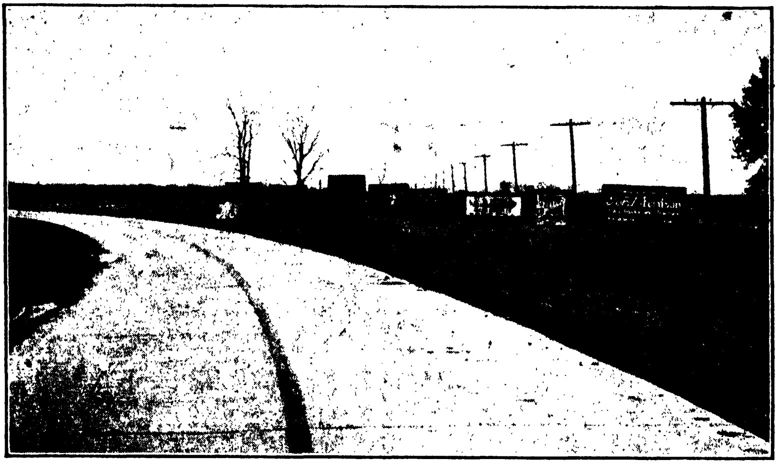


FIG. 20-4.—A help and a hindrance to highway efficiency—the traffic line and the billboard.

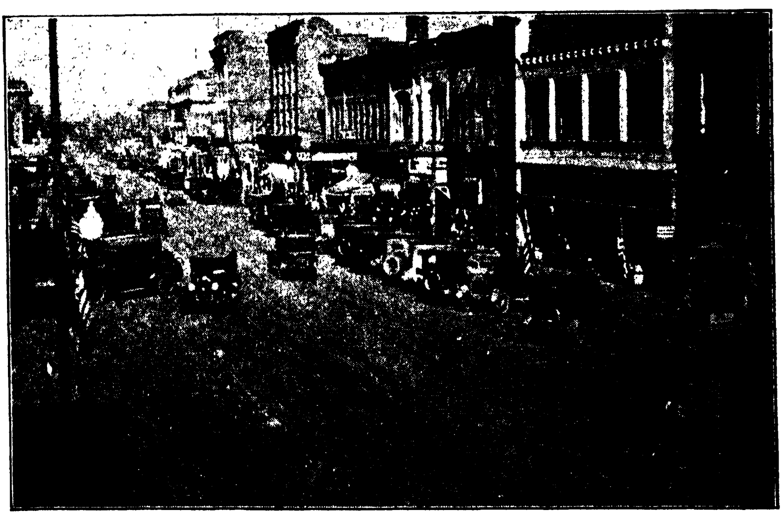


FIG. 20-5.—A traffic jumble, traffic signal, no left turn, diagonal parking, street-car tracks, and safety zone. Note the running traffic in the track area and the automobile turning out to pass the safety zone with no street car in sight.

Safety Zones.—Safety zones are provided on city streets to aid pedestrians in crossing, or at loading points of streetcars and busses. They should be adequate for the number of pedestrians to be accommodated but should avoid all excess. Pedestrians should be required to stay in them but loading zones should not necessarily be inviolate to motor traffic when not occupied especially when streetcars are infrequent (see Fig. 20-5). To make them so complicates traffic, reduces the street capacity, and concentrates traffic to the damage of the pavement.

Hand Signals.—Hand signals by the driver for indicating his car movements early came into use. The closed car has, however, made them practically impossible. Several mechanical signal devices have been invented but the inconvenience of operating or more often the excessive price asked for them has limited their use. If the drivers keep to the right for right turns, to the left for left turns, and slow down gradually there is little need for hand signals.

Police Patrols.—Police patrol of highways is a necessity to enforce traffic regulations of all kinds, aid traffic movements, and protect the public.

On city streets this duty is discharged by the regular municipal police force. In large cities a special traffic squad is organized for traffic control. This squad should be specially selected and trained for the work. Traffic regulation, however, should not be left to the ordinary police department. The entire organization from patrolman to traffic engineer should be in a specially organized department closely affiliated with the engineering department. In the smaller city the time is fast coming when the old type of police force will be replaced by a motorized corps. A half dozen men on motorcycles are worth several times their number on foot in general crime prevention, not to mention the aid to traffic regulation.

On rural highways the patrols are usually limited to the heavy traffic roads. The primary object is to facilitate operation of the road by regulating traffic, repressing the careless driver and "road hog," and watching for defects, washouts, etc., that might prove dangerous. The secondary duty is to repress lawlessness of all kinds. These duties may be discharged by a special highway police under the jurisdiction of the state highway department or by a regularly organized state constabulary. Where a state constabulary exists, a special division should be

assigned to traffic duty under the immediate orders of the highway department. There are certain advantages in having an organized constabulary but it is a fundamental mistake to have the road patrol under the orders of anybody other than the one directly responsible for the operation of the highways.

Railroad Grade Crossings.—Owing to physical limitations, railroad grade crossings will continue to exist on our highways for many years. Each crossing is a potential danger point and the danger must be minimized to the fullest possible extent. All crossings should be so made as to require the minimum of mental or physical effort from the driver in handling his vehicle. Ample sight distance should be provided and all objects which

FIG. 20-6.—A good signal in the wrong place. Note the restricted traffic lanes and the obstruction the signal offers to movement in emergency.

would tend to reduce the visibility of the train removed. Some form of warning signal should be installed positively to indicate the position of each track and the approach of a train.

Figure 20-6 shows incorrect crossing protection. The width of pavement is reduced about 4 ft. and cut into two narrow lanes which constantly distracts the driver's attention and also hampers his movements in a case of emergency. The signals would be more effective at the side of the pavement and would not obstruct the roadway.

Accident records show that a large percentage of the accidents involving trains and automobiles are the result of the motor car hitting the train. This is especially true at night. Observations show that a freight train is not visible under the headlights of an

automobile at a sufficient distance to enable the driver to stop at ordinary road speeds. Some means of increasing the night visibility at railroad crossings is greatly needed.

Crossing Signals.—Crossing signals are used to indicate to the driver the existence of a crossing and the approach of a train and then leave it to him to protect himself. They vary from the ordinary warning board or painted marks on the pavement to elaborate signals with swinging arms and flashing lights. Each signal should be located at such a point and in such a manner as to be visible at a sufficient distance for the driver to bring his vehicle under control before reaching the track, probably not less than 600 ft. It should be of such a type as to distinctly call attention to itself and then clearly indicate the existence of the crossing. In addition to the main signal there should be some device indicating the exact position of each track. This is especially true for multiple tracks. Many accidents occur by failure to observe the presence of more than one track. The visible signal is usually made with red light but, as previously pointed out, these may be nearly invisible to a certain group of drivers affected with protanopia.

Crossing signals that indicate the approach of trains are operated by electricity. The circuit is completed by the train at a certain point in advance of the crossing. The distance should be such as to provide a satisfactory time interval between the starting of the signal and the arrival of the train. Unfortunately the wide variation in train speed makes a distance which is satisfactory for high-speed passenger trains entirely too long for a slow freight and detracts from the effectiveness of the signal. This is the worst drawback to the automatic crossing signal.

Flagmen.—Some crossings are protected by flagmen whose duty it is to warn and stop all vehicles on the approach of the train. The human element makes it possible to allow for train speeds. On very busy crossings a flagman is about the only satisfactory device for handling traffic.

Crossing Gates.—Many busy crossings, especially in cities, are protected by gates operated by a watchman. The gates are simply a mechanical device to make more effective the signal of the watchman. Neither the flagman nor the gates are foolproof and accidents often occur at such crossings. One of the worst defects both with the ordinary flagman and with the gates is the

tendency to discontinue operation at night, thus leaving the crossing unprotected during the hours of darkness.

Crossing gates are painted in alternate bands of black and white.[1] This is presumed to give them higher visibility but under certain conditions of background actually amounts to a form of camouflage. The addition of a band of some brilliant color would relieve this defect. A brilliant tangerine orange is one of the best colors for this purpose. Lights should be attached to the gates at night. Red or green is the usual color. On wide streets there should be more than one light on each gate. In a few cases the gates and crossing have been flood lighted. This is effective but expensive.

Grade Separation.—The only method of preventing interference of rail and highway traffic is to separate the grades. This may be done by an *overpass* or *viaduct* or by an *underpass* or *subway*. And even here care must be taken or the device may be as dangerous as the original crossing. Grades and alinements must be such as to give an ample clear sight distance. The structure itself must not impose restrictions on the highway. With an undercrossing there should be no supports for the tracks placed in the roadway if it is physically possible to eliminate them (see Figs. 14-7, and 14-8).

Marked Routes.—The demand for some means of following roads long distances without going astray antedates the establishment of the state highway systems. The early demand was met by the marked trail. A few were well conceived, and their names, such as the *Lincoln Highway*, may persist long after their marks have disappeared.

The establishment of the state systems introduced the numbered routes with a definite marker for all roads included in the system. This was a decided improvement over the old scheme. The demand for longer routes than just within a single state led to the establishment of the federal system of interstate highway commonly called *U. S. Routes* (see Fig. 20-7).

The routes should be carefully marked. The test of good marking is whether a total stranger can follow the route, using reasonable care, without hesitating or getting off it. Marking through cities is especially difficult. The markers must be so placed as to be visible but not to disfigure the street or to interfere with its use. Junctions should be distinctly indicated.

[1] Interstate Commerce Commission regulations.

Another very important point that is often neglected is the placing of suitable signs at occasional intervals indicating the direction or terminal toward which the traveler is going.

Highway Signs.—To facilitate the movements of traffic, highway signs are employed. They may be classified as informational signs, directional or warning signs, and route markers.

Informational signs are those giving information relative to location, distances, speed limits, cities, etc., which are of value to the traveler but do not relate to the immediate or detailed control of the vehicle. The standard shape is rectangular with the longer axis either horizontal or vertical.

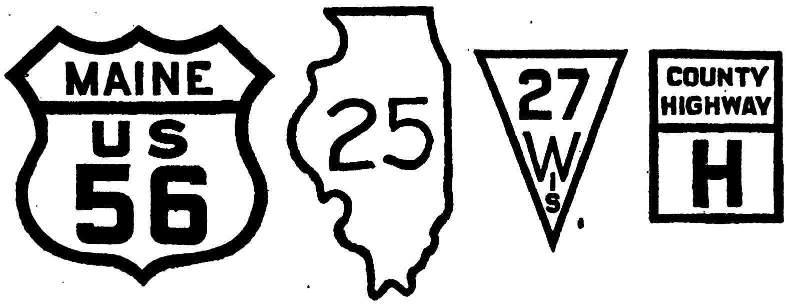


FIG. 20-7.—Types of route markers. The preferred color is black on white.

Directional signs are those that give information necessary to the operation of the vehicle; hence the name *warning signs*. They are divided into two groups. First, those indicating conditions requiring readiness to act on the part of the driver but not necessarily a specific action, such as school zone, business district, underpass. The standard shape for these signs is square. The second group indicate conditions requiring some definite action by the driver. They include curves, grades, danger points, etc. The standard shape is the diamond or square with its diagonals vertical and horizontal. One sign in each group has a special shape, the round railroad crossing sign and the octagonal stop sign.

Route markers are used to indicate a particular route or road. They consist of some distinctive outline enclosing a number or letter indicating the particular road. State outlines are very popular for indicating state road systems. Only a few states, however, have shapes sufficiently distinctive to be good markers. The color combination is black and white with a few exceptions.

Route markers should be set at all junctions and at cross roads or streets. They should also be placed at reassuring intervals where junctions or cross roads are far apart. They may be placed on posts with other signs or on separate posts. The position should be at the shoulder line since they are practically invisible at night if placed beyond the ditch. They should be placed on both sides of the roadway. When placed on one side only they are practically invisible in one direction by night and intervening vehicles may hide them by day. They should be turned toward the roadway through an angle of about 30 deg. to make them more legible and kill the glare at night.

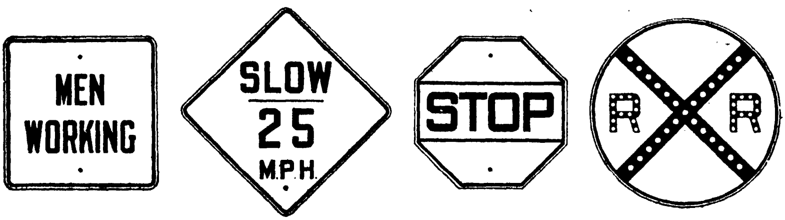


FIG. 20-8.—Typical standard warning signs. The preferred colors are black on yellow. The railroad sign shows the use of reflector buttons.

Visibility of Signs.—The visibility of a sign governs its effectiveness. *General visibility* relates to the facility with which the sign can be picked out from its surroundings. It depends on the size, shape, color, height, and location of the sign. *Specific visibility* expresses the facility with which the exact indication of the individual sign can be obtained. It depends on the shape, color, size, wording, and the size and style of lettering.

Shape and Size.—The shape of a sign has some effect on its visibility but the effectiveness of shape as an aid to traffic has been overestimated. Figure 20-8 shows the code of shapes for warning signs recommended by the American Society of State Highway Officials and which has been widely adopted. The basic size of these signs is 24 by 24 in. with larger sizes increasing in increments of 6 in.

The diamond sign has the highest general visibility because it has the largest horizontal and vertical dimensions and its boundaries cut across the normal lines of nature. This value is lost, however, since there are over 20 different indications made by word or symbol on this shape. The shape can mean little when the driver must of necessity pick out from the sign itself some one

of more than a score of possible messages. The square sign is next in visibility, since it has the same area, although its dimensions and position of boundaries are not so favorable. The octagonal and round signs lose visibility by decrease in size, since the area of the octagon is only 83 percent and the circle 78½ percent of the square. Each of these bears but a single indication but the two signs cannot be distinguished from each other by shape at a distance of a few hundred feet. Many people do not recognize the difference so after all the message is delivered by the legend and not the shape. The railroad sign is improved by making the cross at 45 deg. instead of as shown, thus giving it the same form as the regular crossbuck sign set by the railroads so familiar to everyone.

Color Combinations.—Innumerable color combinations are possible and many have been tried. Black, white, red, orange, and yellow are the colors which predominate. Black and white has the highest specific contrast and reflecting powers. On the other hand, the combination tends to blur to gray and also weathers to gray. Irradiation tends to cause black letters on white ground to appear smaller than they actually are. Such signs also lack general visibility in daylight against the ordinary backgrounds and especially so against snow, but the visibility is high at night.

Red with white blurs to pink and to orange with yellow. Although highly visible in bright daylight, red loses visibility rapidly at dusk and therefore is not suitable for signs except in combination with other colors on danger signs. A danger sign composed of black, yellow, and red is very brilliant and much more effective in all lights than the ordinary two-color sign.

Black and yellow do not blur to another color and the colors stand the climate well. Yellow letters on a black ground have the highest specific visibility but black letters on a yellow ground with a black border form a sign of highest general visibility against all backgrounds by daylight. With a suitable yellow the night visibility is satisfactory and therefore this combination appears the best for road signs, especially warning signs, and has been adopted by the American Association of State Highway Officials. The standard color is known as *federal yellow* and lies between lemon yellow and light chrome orange.

Height.—The combination of low car tops and low headlight beams requires signs of low height. Experiments by the

author[1] indicate a desirable height of 39 in. above the roadway to the middle of the normal road sign and not more than 6 ft. to the top of any sign dependent on the headlights for illumination. The American Association of State Highway Officials has adopted a height of 42 in. to the middle of normal signs which is entirely satisfactory. On city streets where the sign must be high enough to clear pedestrians or parked cars, some form of illumination other than the headlights is required.

Location.—Signs should be always set where they can be best seen. On rural roads safety demands that they be set near the shoulder line. On city streets they should be set with the near edge over the curb, unless they have sufficient height to clear traffic.

Where successive signs are required, they should be placed in the order in which they are to be obeyed. Nor should the indication of one sign carry past that of another. Signs should not be placed at unduly long, or at too short, distances from the point to which they apply. On the open road signs should be so placed that they can be comprehended and obeyed at normal road speeds. This calls for a distance of about 400 ft. Stop signs should always be placed at the point of stopping with an advance sign about 400 ft. in advance.

On city streets, running is essentially block by block. Therefore no sign should be placed in any block which applies to the block beyond. Normal spacing of signs as used on the open road must therefore be modified when the marking is carried through a city. As a driver approaches an intersection his attention centers on clearing that intersection, and preceding signs are forgotten. As soon as he is clear of the intersection he looks ahead for conditions in the new block and here is the proper place to locate signs for the new block. The signs should then be placed in the order they are to be obeyed. It cannot be expected that a driver will keep in mind a series of signs. The rule should be strictly one at a time. Route markers are the only exception. They should be placed frequently enough on open roads to be seen at short intervals. On streets there should be at least one in sight at all times.

Position.—Signs are usually placed nearly perpendicular to the road. When they are so placed a glare from the headlights is

[1] Road Signs for Night Driving, *Roads and Streets*, Vol. 76, No. 2, p. 75, February, 1933.

developed that often makes the legend of the sign invisible. It requires the application of only the simplest laws of optics to show why this occurs. The glare can be eliminated by turning

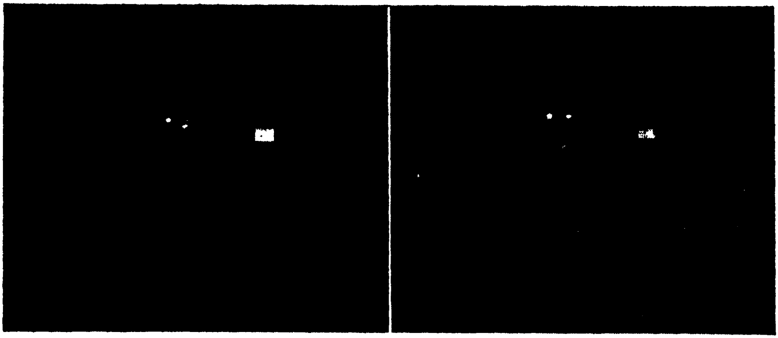


FIG. 20-9.—Glare eliminated by turning the sign 30 deg. toward the roadway.

the sign toward the road through an angle of about 30 deg. or so its face makes an angle of 60 deg. with the center line of road.[1] The glare is thrown across the road and out of the driver's eyes. At the same time the sign is presented at a better angle for reading; hence its visibility is improved both by day and by night. The glare can also be killed by tilting the sign forward about 5 deg. The tilt can be combined with the angle, resulting in an entirely glare-free position. So effective is this method that many signs now being reflectorized could be made plain at a considerable saving in cost.

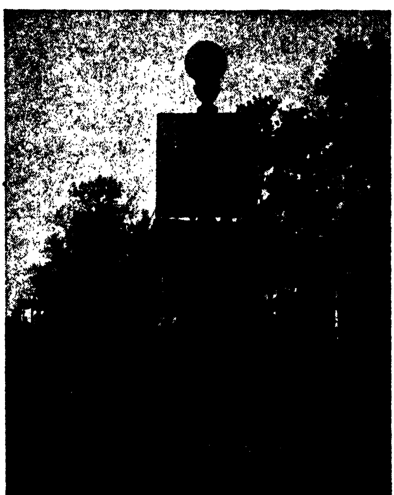


FIG. 20-10.—Direction signs.

Wording.—The wording should be the simplest possible. All extraneous words should be carefully eliminated. Standard abbreviation should be employed wherever possible. A good rule to follow in lettering a sign is "in case of doubt leave it out." The general tendency is to put too much on a sign. Experi-

[1] *Ibid.*

ments indicate that about 10 letters is the maximum number that can be read while passing a sign at road speeds except where combined into common words. Three or four names of cities may be picked up but if followed by distances only two or possibly three can be grasped. Symbols should be substituted for words wherever possible. A large curved arrow indicates a curve much more effectively than the word curve.

Street Names.[1]—Posting of street names is highly important in cities. They may be placed on special plates attached to special posts or to existing light, telephone, or other poles. Where large white globes are used on street lights the names may be painted on the globes to good advantage. Another system is to paint the names on the curbs on the far side of each intersection.

A.A.S.H.O. Type. Illinois Type.

FIG. 20-11.—Arrows. The A.A.S.H.O. arrow has been enlarged 12½ percent to give it the same shaft width as the Illinois arrow but even when enlarged its effectiveness is only about 70 percent compared with the other.

The letters can be made quite large and in easy sight of both pedestrian and vehicle drivers but the visibility at night is not good unless the streets are well lighted. Furthermore, snow or dirt may obstruct the view.

Arrows.—Arrows are an important part of directional signs. To be of service the arrows must be highly visible and their direction of flight unmistakable. Many arrows are too "artistic" to serve this purpose when viewed from the seat of a moving automobile.

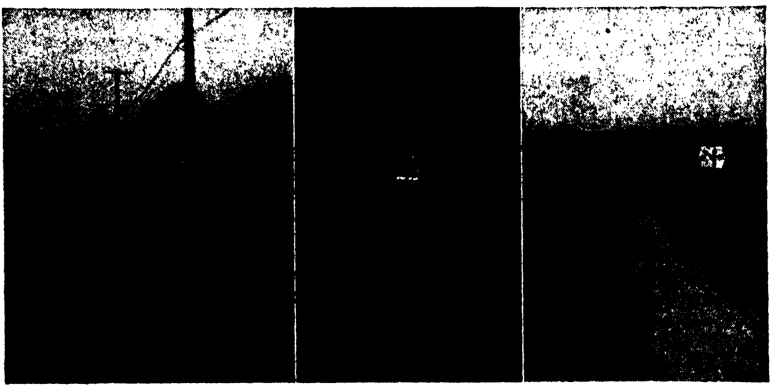
The arrow should be simple in outline, heavy, and free from sharp points and fine lines. The most effective arrow, although lacking somewhat in beauty, is the Illinois arrow shown in Fig. 20-11. It is distinctly visible at distances at least 50 percent greater than the standard A.A.S.H.O.[2] arrow shown in the same figure.

Junction Signs.—Probably the weakest point in the marking of highways is at junctions. The ordinary sign bearing the word

[1] Street Names and House Numbers, *Civil Eng.*, Vol. 2, No. 3, p. 186, March, 1932.

[2] American Association of State Highway Officials.

Junction has such low visibility and is usually set so close to the junction that it has little real value. The driver should be informed of the junction far enough in advance to make any movement that may be required. This calls for an advance sign of definite significance. If shape is of any advantage, here is the place for a distinctive shape to be used nowhere else. An elongated hexagon as shown in Fig. 20-12 seems suitable. Probably the best symbol, although little used in the United States, is a conventionalized map of the junction, as also shown in Fig. 20-12.



A *B* *C*

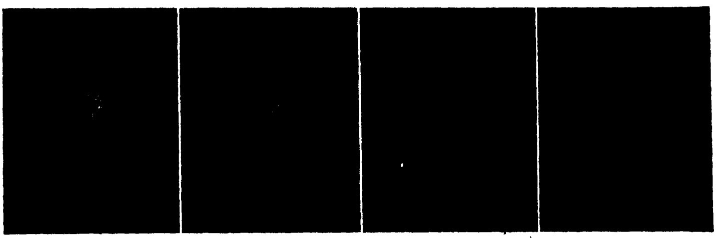
Fig. 20-12.—Junction sign using symbols instead of words. *A*, a reflectorized sign at a T-junction with sharp turns; *B*, the same sign at night; *C*, a plain sign at a Y-junction with easy curve set at 60° to kill glare at night.

Reflectorized Signs.—For greater effectiveness at night many signs are now *reflectorized* by inserting *reflector buttons* in the words or symbols. These buttons consist of three essential parts, the shell, which includes the means of locking the button in the sign, the glass lens, and the reflector. They are so made that they reflect the light from the headlights directly back toward the driver. They can be had in several sizes and colors. Red is used for stop signs and is to be preferred to any other color. Green does not show well and is little used. Amber is a little too dark. White gives the strongest reflection but may be confused with other lights. Accidents have actually occurred by mistaking a fixed reflector for the headlights of another car or by failing to see the sign because the white reflection was lost in the lights of a filling station. Railroads long ago abandoned white as a signal light for train operation. A light yellow color has also

been used. It gives a strong reflection but the color is not quite distinct enough. A color between this yellow and amber seems to offer possibilities.

The buttons should be of such size and spacing as to show the symbol it is in distinctly. Arrows are made more effective at night by placing the buttons outside the head rather than inside as is usually done (see Figs. 20-12 and 20-13).

The *Ross Traffic Marker* is a form of reflectorized sign used for marking the traffic line, especially on curves. It consists of a low steel turtleback with reflector buttons in the ends anchored in the pavement. Markers are placed at suitable intervals to outline the traffic line and are very effective when kept clean.



A *B* *C* *D*

FIG. 20-13.—Reflectorized signs and arrows. *A* and *B*, standard A.A.S.H.O. signs fully reflectorized and with buttons inside arrow heads; *C*, standard A.A.S.H.O. curve sign with only the arrow reflectorized with buttons outside the head; *D*, Illinois type of arrow with buttons outside the head.

Illuminated Signs.—In cities and special locations dependence should not be made on the headlights for illuminating the signs, even by reflectorizing. Such signs should be illuminated either by flood lighting or, preferably, by internal lighting. Neon tubes have been developed for this purpose, as have slow-drain storage batteries for use where electric power is not available.

Parking.—When vehicles are stopped and left standing without a driver they are said to be *parked*. Parking is an essential and fundamental part of highway traffic. But just as traffic movement is subject to regulation, so must parking be controlled so that the highway will yield the maximum service to the greatest number. The parking problem is therefore an integral and important part of the traffic problem.

Parking Time Limits.—In congested areas it is customary and logical to limit the time which a vehicle may remain parked. The limits are usually arbitrarily made and often without a care-

ful consideration of the needs. Either a needlessly long or a needlessly short limit has an adverse effect on traffic. The proper time limit should be such that the average person can park his vehicle, walk the normal distance to a place of business, have a reasonable time to attend to his transactions, and return to the vehicle. Under the most favorable conditions, 30 min. is about the minimum, and the larger the area involved and the greater the congestion the longer the time required with perhaps 1 hr. as a maximum. In front of certain buildings, such as post-offices, the time limit may properly be reduced to as short as 10 min., since it is presumed that only the patrons of this building will stop there and will require only a few minutes and then move on to other points.

Parallel Parking.—On narrow streets parking parallel to the curb is a necessity. This requires a minimum width of about 8 ft. and a length per car of 18 to 20 ft. In crowded areas the parking spaces should be distinctly marked and some police supervision may be necessary to overcome carelessness. It is a sad commentary on motorists that the large majority park as if no one else were on the street and might desire to stop also. The driver who does not park his car within the minimum space, or who stops short of or overruns the ends of the parking spaces is stealing from the rights of others. He is a variety of road hog.

Diagonal Parking.—Where street widths permit diagonal parking, an angle of 45 deg. is the most convenient and economical. The width of stalls should be about 8 ft., which requires a curb space of about 11 ft. to which must be added about 10 ft. more for the last car in the group. The street width required is about 15.5 ft. for the ordinary automobile. The very large car or truck requires a greater width.

At the forward end of a block the vehicles may be parked well up to the sidewalk line, while at the rear of the block a longer space must be reserved so that the last car will not project into the path of turning traffic.

Right-angle Parking.—Parking at 90 deg. with the curb permits the largest number of vehicles per block to be parked but requires a wider street, partly because the vehicles project somewhat farther into it but more particularly on account of the space required for the vehicle to make a 90-deg. turn into its stall. This method, therefore, can be used only on very wide streets.

Center Parking.—Sometimes on wide streets parking is done in the middle at an angle of 45 or 90 deg. This method leaves the curbs free for vehicles to stop to load and unload. Unless

TABLE 20-3.—NORMAL CURB SPACE IN FEET REQUIRED FOR PARKING AUTOMOBILES

Number of automobiles	Parking angle			
	0 deg.	30 deg.	45 deg.	90 deg.
	Street width required, 8.0	Street width required, 14.5	Street width required, 15.5	Street width required, 16.0
1	15	15	15	8
2	33	31	26	16
3	52	47	37	24
4	71	63	48	32
5	90	79	59	40
6	109	95	70	48
7	128	111	81	56
8	147	127	92	64
9	166	143	103	72
10	185	159	114	80
11	204	175	125	88
12	223	191	135	96
13	242	207	147	104
14	261	223	158	112
15	280	239	169	120
16	299	255	180	128
17	318	271	191	136
18	337	287	202	144
19	356	303	213	152
20	375	319	224	160
21	394	335	235	168
22	413	351	246	176
23	432	367	257	184
24	451	383	268	192
25	470	399	279	200
26	489	415	290	208

the street is sufficiently wide so that two tiers of cars can use the middle, the capacity is the same as parking on one side only. Center parking divides the running traffic into two lanes which may be objectionable unless the pavement is quite wide, and running traffic of only moderate density.

Double Parking.—When vehicles stand outside the regular parking space so as to form two tiers, it is termed double parking. This reprehensible habit is evident in some cities and is evidence of both laxness in supervision and of the presence of a variety of road hog. In general, double parking is due primarily to laziness, both of the drivers and of the police force.

Parking Areas.—Where there is a large demand for parking space, especially if it is to be occupied continuously for several hours by the same vehicles, other areas than the streets must be provided. These may be supplied by the municipality or by private enterprise. In the latter case there is normally a fee, and there may be in the former. This is an important problem in the large cities. In some cases, buildings are being designed with parking floors.

Road Maps.—An exceedingly important part of highway operation is the issuance of road maps and other information. Nearly every state now issues, at frequent intervals, road maps showing the location of the trunk roads, the numbering system, and road classification or condition. Some of the maps are supplemented by bulletins giving more detailed information.

These maps are properly issued by the highway authorities and not by private enterprise. Some authorities have not issued maps and the deficiency has been met by the oil companies and motor clubs. Many of these commercial maps are very good.

Road maps should be made on accurate base maps showing the railroads and principal streams. In addition to information relating to the roads, they should include such information as population of cities, distances between major points both within and without the state, points of interest, state and national parks, etc., and any other information of particular importance, such as danger points, water and supply stations in arid or sparsely populated regions.

Public Utilities.—The streetcar problem is quite difficult. Since the cars move on fixed rails, the system lacks flexibility and the general effect on traffic and street capacity is considerable. Not infrequently streetcar systems reduce street capacities more than is warranted either by the service rendered or the financial returns.

Busses and trackless trolleys mingle with the other traffic and offer less interference, especially if stops for passengers can be made at the curbs. They are, however, destructive to pave-

ments, and franchises for their operation should provide adequately for their just share in the upkeep.

Interurban electric railway lines are occasionally found in public highways but this is highly objectionable, unless the right-of-way is quite wide and special provision for the tracks is made. Almost invariably such a system adds a number of grade crossings.

Telephone, telegraph, and similar utilities may be granted franchises on rural highways. The conditions of such permits should be in the hands of, or be approved by, the highway officials. High-voltage transmission lines should never be permitted on public highways.

City streets are the natural rights-of-way for all utilities, but they should be controlled by franchise granted by the city.

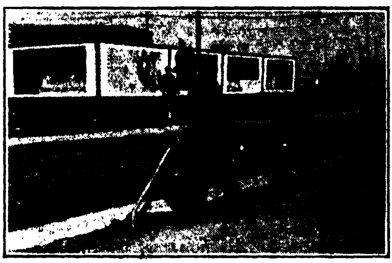


FIG. 20-14.—Cleaning gutters by hand.

Cleaning.—Cleaning is an important item in the operation of city streets. Debris and dirt of many kinds are sure to collect on the pavements and must be removed for the sake of appearance, convenience, and sanitation. Street cleaning is done by gangs organized especially for that purpose and not by the regular maintenance forces.

The simplest method of street cleaning is to collect the dirt into piles by means of brushes, brooms, shovels, or small scrapers drawn by horses, and then shovel it into wagons or trucks to be hauled away. Sometimes the dirt is washed into the storm sewers and catch basins by means of power flushing machines or fire hose. This method is generally effective as far as cleaning the surface but it increases the work of cleaning the catch basins and runs the danger of clogging the sewers. Various kinds of power cleaners are employed in larger cities. The object is to collect the waste material as thoroughly and quickly as possible without interfering with the use of the street and without making the work a nuisance to the traffic and residents. Street cleaning in

the larger American cities ranges from 2 to 20 cts. per square yard of pavement per annum.

Little cleaning is required by rural road surfaces. The rain usually suffices to clean the surface so that the cleaning work is almost wholly confined to removing debris and silt that tend to clog the drainage channels. This work is done in the regular course of maintenance procedure and therefore does not require a separate crew and generally is not considered a separate process.

Snow Removal.—Snow removal has long been an important problem in the large cities. It is essential that traffic can operate without serious delay; therefore the snow must be promptly and

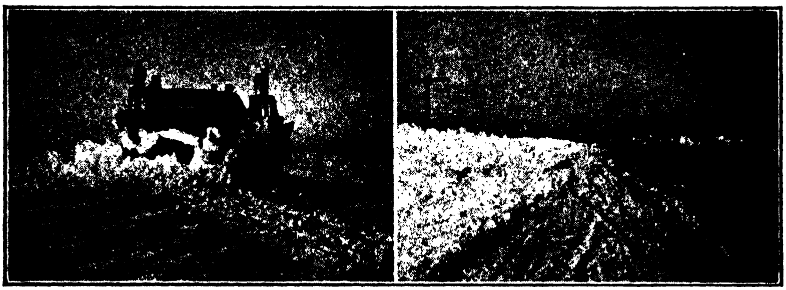


FIG. 20-15.—Snow removal on a trunk highway.

almost completely removed. Sometimes the snow is merely pushed aside with a blade grader or snow plow to form a traffic lane and left to melt. Sometimes it is collected into piles and then loaded into wagons or trucks and hauled away and dumped in waste places, or into streams or storm sewers. In some cases when the snow is soft it can be washed into the sewers with fire hose. Many special devices have been developed for the rapid opening of traffic lanes, and for the collecting and disposing of the snow. The cost of the work is quite variable, depending on the frequency and depth of snowfall and the facilities for doing the work.

With the advent of the automobile and the resulting demand for all-year service, snow removal has become an important operation on our main highways in the snow belt. This work is usually done by the maintenance forces although specially organized crews and special equipment are required. The equipment ranges from ordinary hand shovels to elaborate snow plows, some of which are of a rotary type. A blade grader or a light one-way truck plow can do effective work in snowfalls of 4 to 6 in.,

provided the snow is not badly drifted. For heavier falls and drifts, snow plows mounted on heavy trucks are generally used. For deep drifts, the rotary plow may be desirable. Care should be exercised in the design and construction of the road to reduce the tendency to drift, as much as possible. The judicious use of snow fences will also materially aid in simplifying the snow-removal problem.

With only occasional snowfalls, it is sufficient to push the snow aside to provide a double-traffic lane. Where successive falls are expected, the first fall should be pushed as far from the traveled way as possible. Later snowfalls are pushed on top of the preceding ones as much as possible but at best the lane will gradually narrow and trouble may be experienced in seasons of heavy snowfall in keeping an adequate space for a traffic lane.

The slogan for snow removal on either road or street should be *Keep traffic moving.* To do so requires that equipment be provided, the gangs well organized, and the various operations perfectly synchronized. When a storm begins, the work should start promptly and be kept up continuously so that the accumulation will never become so deep as to stop traffic.

Detours.—Detours are the bane of the motorist. Nevertheless, construction and repair work frequently require a road to be closed and a detour is the only means of keeping traffic moving. Detours are always expensive and therefore should be given careful attention to reduce the cost. The economic losses due to increased distance, poorer surface, greater maintenance cost, etc., are astounding.

The route and nature of the detour should be studied at the same time as the new work is designed. Often a change in construction section limits, or in the order of procedure, will facilitate the handling of traffic. The route selected for the detour should be the shortest and best obtainable. It should first be put into as good condition as possible and throughout its use be maintained to the best its character will permit. It should not be placed in service until absolutely necessary and it should be abandoned at the earliest possible date. And last, but not least, it should be plainly and thoroughly marked. The cost of operating the detour is a legitimate charge against the improvement.

Barricades.—Whenever a road or street is closed for any reason, barricades are necessary, both to protect the public and to

prevent damage to the work or to the workmen. Such barricades should be substantial and durable. They should be so placed that traffic can be diverted with the least inconvenience, and each should bear a distinct warning sign indicating the reason for closing. More important, however, is a proper detour sign. At night the barricades should be indicated by lights. Usually red lanterns are used. Owing to the multiplicity of red lights on the rear of automobiles some other color might be preferable.

FIG. 20-16.—Protecting traffic at night. Warning lights on obstruction.

The flare torch may be more effective than the lanterns. Enough lights should be placed to make the barricade distinct so that a driver will not attempt to go around. This is very likely to occur if only a single light is used.

Obstructions.—Obstructions of all kinds, such as ditches, piles of material, and machinery, should be set off by barricades and distinctly lighted at night. Dangerous places, such as washouts, should be similarly protected. Here again red lights are ordinarily used but are defective in that they offer no illumination of the obstruction. The open flare torch is gaining in favor because there is no danger of mistaking it for the rear light of an automobile, it offers some illumination to the ground, is visible to everybody, and contractors find there is less loss from breakage or theft.

Street and Highway Lighting.—Crude attempts were made in the earliest days to light city streets, primarily for the benefit

of pedestrians. The introduction of coal gas was a great improvement but it was not until the invention of the electric arc lamp and suitable electric generators that street lighting became general and reasonably satisfactory, even with horse-drawn vehicles. The introduction of the automobile made street lighting even more imperative for the safety and convenience of both the pedestrian and the motorist. The development of the incandescent lamp and the improvements in power generation and transmission have made street lighting almost universal and highly efficient.

The steady increase in night driving has brought with it the demand for better illumination of the rural highways, especially those carrying large volumes of traffic. Some attention was given to road lighting as early as 1910 but most of the development in this field has been since 1925. Several trial installations have been made and numerous experiments have been undertaken, but on the whole highway lighting is still (1935) in its infancy.

Street and highway lighting involves many technical problems which belong more to the field of electrical engineering than that of highway engineering and therefore can not be treated here. The reader is referred to the various treatises on electricity and illumination. Furthermore, no installation of either street or highway lighting, no matter how small, should be undertaken without consulting a competent illumination engineer.

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